Missouri Department of Natural Resources Water Protection Program

Total Maximum Daily Load (TMDL)

for

Little Osage River Vernon County, Missouri

Completed: February 25, 2010
Approved: June 10, 2010

Total Maximum Daily Load (TMDL)
For Little Osage River
Pollutant: Low Dissolved Oxygen

Name: Little Osage River

Location: North of Nevada in Vernon County, Missouri

Hydrologic Unit Code: 10290103

Water Body Identification: 3652

Missouri Stream Class: C [1]

Designated Beneficial Uses:

- Livestock and Wildlife Watering
- Protection of Warm Water Aquatic Life
- Protection of Human Health (Fish Consumption)
- Whole Body Contact Recreation – Category B

Location of Impaired Segment: Sec. 18, T37N, R31W to Section 18, T37N, R33W

Length of Impaired Segment: 23.6 miles[2]

Use that is impaired: Protection of Warm Water Aquatic Life[3]

Pollutant: Low Dissolved Oxygen

TMDL Priority Ranking: High

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[1] Class C streams may cease flow in dry periods, but maintain permanent pools which support aquatic life. See Missouri water quality standards 10 Code of State Regulations [CSR] 20-7.031(1)(F)6. The water quality standards can be found at: www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf

[2] Listed as impaired on the 2008 303(d) List for the class C water body length of 16 miles. Length of this water body segment is revised in 10 CSR 20-7.031 Table H to 23.6 miles, effective October 2009. This revision reflects a more accurate measurement of length. The location and the starting and ending points of this segment have not changed. Revisions to 10 CSR 20-7.031 have not been approved by the U.S. Environmental Protection Agency at the time of TMDL submittal.

[3] The impaired use is incorrectly identified as Whole Body Contact Recreation on the 2008 303(d) List. This will be corrected to Protection of Warm Water Aquatic Life on the 2010 303(d) List.

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Tables

1 Introduction

This Little Osage River Total Maximum Daily Load, or TMDL, is being established in accordance with Section 303(d) of the federal Clean Water Act. This water quality limited segment near Nevada in Vernon County, Missouri is included on the U.S. Environmental Protection Agency, or EPA, approved Missouri 2008 303(d) List of impaired waters.

The purpose of a TMDL is to determine the pollutant loading that a water body can assimilate without exceeding the water quality standards for that pollutant. Water quality standards are benchmarks used to assess the quality of rivers and lakes. The TMDL also establishes the pollutant load capacity necessary to meet Missouri water quality standards based on the relationship between pollutant sources and instream water quality conditions. The TMDL consists of a wasteload allocation, a load allocation and a margin of safety. The waste load allocation is the portion of the allowable pollutant load that is allocated to point sources. The load allocation is the portion of the allowable pollutant load that is allocated to nonpoint sources. The margin of safety accounts for the uncertainty associated with water quality model assumptions and data limitations.

The Little Osage River was first placed on Missouri's 303(d) List of impaired waters in 1998 by the EPA, citing "natural background" conditions. The impairment was changed to low dissolved oxygen on the 2002 303(d) List, with the source of the impairment unidentified. The Little Osage River is currently on EPA-approved 2008 303(d) List for low dissolved oxygen for the entire length of the class C segment, with the source of the impairment still unidentified. It is also listed on the state's 2008 303(d) List for not meeting water quality criteria related to *E. coli* bacteria. A TMDL to address this impairment will be completed at a later date.

The Little Osage River has also appeared on the Kansas 303(d) List since at least 1998, where it was listed for violation of the state's water quality criterion for fecal coliform. A TMDL to address this impairment was approved by EPA in 2001. Currently, the Little Osage River is on Kansas' 2008 303(d) List of impaired waters for aquatic life impairments related to copper, lead, and dissolved oxygen.

2 Background

This section of the report provides information on the Little Osage River (Little Osage) and its watershed.

2.1 The Setting

The Little Osage River originates in Kansas, in southeastern Anderson and northeastern Allen Counties, and flows in an easterly direction toward Missouri. In addition to Anderson and Allen Counties, the Little Osage watershed includes part of Linn and Bourbon Counties in eastern Kansas, and Vernon and Bates Counties in Missouri. Just north of the city of Nevada, Missouri, the Little Osage is joined by the Marmaton River, and then further downstream the

Marais des Cygnes, to form the Osage River. The main stem of the Little Osage flows for roughly 46 miles through Kansas, where it drains a watershed of approximately 366 square miles. Once in Missouri, the river flows for approximately 39 miles, with a watershed in this state of 217 square miles. Altogether, the Little Osage River is roughly 85 miles long and drains a watershed of about 583 square miles in both Kansas and Missouri (Figure 1).

The impaired length of the Little Osage River in Missouri is 23.6 miles (see footnote 2), the full length of the class C segment. The classified segment corresponds to that portion of the stream defined in Missouri's water quality standards (10 CSR 20-7.031 Table H); the impaired segment corresponds to that portion of the stream determined to not be meeting water quality standards. In this case they are the same length (Missouri Secretary of State 2008).

2.2 Population

Based on spatial analysis by the Department using 2000 census data, the population of the entire Little Osage watershed is approximately 6,604, which equates to a population density of approximately 11 persons per square mile (U.S. Census Bureau 2001). In the Missouri portion of the watershed, the total population is 2,937, with an average population density of 13 persons per square mile. The overall population in Missouri is predominantly rural, with only four small towns scattered throughout. The largest of these, Rich Hill and Hume, with populations of 1,460 and 337, respectively, are bisected by the northern boundary of the watershed. The two smallest towns, Stotesbury and Metz, each have populations under a hundred individuals (Figure 1) (U.S. Census Bureau 2000).

The Kansas portion of the Little Osage watershed can similarly be characterized as a predominantly rural watershed, with only about six small urban centers. Data from the 2000 Census indicates that the population in the Kansas portion of the watershed is 3,667, with an average population density of 10 persons per square mile (U.S. Census Bureau 2002).

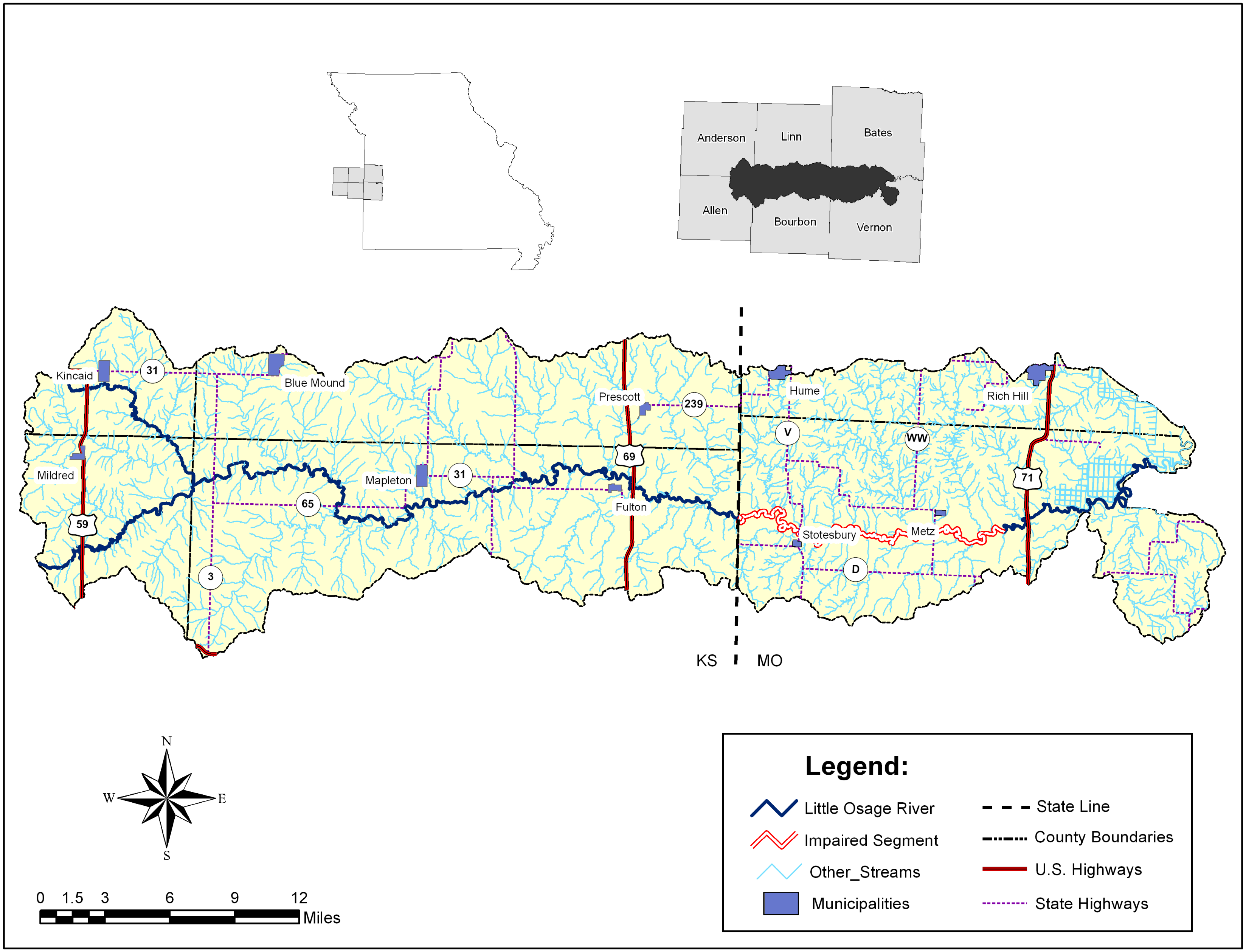

Figure 1. Location of the Little Osage River and watershed (MoRAP 2005, KARS 2008)

2.3 Geology, Physiography and Soils

The Little Osage River watershed in Missouri ranges in elevation from 720 to 970 feet, with slopes ranging from level to gentle in the extensive stream bottoms and some upland areas. Throughout other parts of the watershed slopes range from moderate to steep. Elevations and topographic relief generally increase as the watershed extends west into Kansas. This region is unglaciated and the entire basin is dominated by Pennsylvanian-age bedrock, with alternating deposits of sandstone, shale and limestone.

The lower portion of the basin, near the confluence with the Marmaton and Marais des Cygnes Rivers, falls within the Cherokee Plains ecoregion, a relatively flat erosional plain characterized by claypan soils that are less fertile and more poorly drained than soils in the adjacent Wooded Osage Plains ecoregion. Wide alluvial valleys with abundant wetlands exist in an area that saw presettlement vegetation of both upland and wet prairie, and oak-hickory woodlands. The Wooded Osage Plains ecoregion dominates the western portion of the watershed in Missouri, including the impaired segment, and comprises the majority of the watershed in Kansas (along with a transition into the Osage Cuestas region in the headwaters). This region is characterized by gently rolling upland prairie broken by low limestone escarpments. Although the stream valleys are relatively wide, there is greater topographic relief here – particularly in the escarpment zones – than in the Cherokee Plains. Presettlement vegetation was a mixture of oak-hickory woodlands and bluestem prairie (Chapman, *et al*. 2001 and 2002).

The Soil Survey Geographic database developed by the United States Department of Agriculture Natural Resources Conservation Service, or NRCS, shows that greater than 88 percent of the soils in the Little Osage watershed in Missouri are characterized as having slow or very slow infiltration rates, and roughly 22 percent of the land area is considered highly erodible or potentially highly erodible. Soil groups are represented primarily by Barden, Parsons, and Kenoma silt loams on the hillsides and uplands, ranging from somewhat poorly to moderately well-drained. Zars silty clay and Osage silty clay make up the other dominant soil groups, the latter being mostly level and poorly drained floodplain soils (USDA 1977).

According to Kansas' 2001 TMDL for the Little Osage subbasin of the Marais des Cygnes watershed, average soil permeability within the Little Osage watershed in that state is 0.6 inches/hour (based on the NRCS State Soil Geographic data base). Furthermore, about 98 percent of the watershed produces runoff under relatively low infiltration potential conditions of 1.71 inches/hour, and storms generating less than 0.57 inches/hour still generate runoff from over half the watershed, primarily in the upper and lower thirds of the watershed in the stream channels (Kansas Department of Health and Environment 2001).

2.4 Land Use and Land Cover

The land use and land cover of the Little Osage watershed is shown in Figure 2 and summarized by state in Table 1. The primary land uses for the entire watershed, including both Missouri and Kansas, are grassland (52 percent), cropland (27 percent) and forest and

woodland (15 percent) with open water and urban areas occupying 1.2 and 0.7 percent of the watershed area, respectively. While roughly 10 percent of the watershed in Missouri is classified as wetland, the majority of this land cover type is downstream of the impaired segment.

Table 1. Land use/land cover in the Little Osage watershed (MoRAP 2005, KARS 2008)

Land Use/ Land Cover	Missouri			Kansas			Entire Watershed		
	Watershed Area			Watershed Area			Watershed Area		
	Acres	Square Miles	Percent	Acres	Square Miles	Percent	Acres	Square Miles	Percent
Urban	1658	2.6	1.2	1138	1.8	0.5	2797	4.4	0.7
Cropland	49421	77.2	35.7	49978	78.1	21.3	99399	155.3	26.7
Grassland	57570	90	41.6	134785	210.6	57.5	192356	300.6	51.6
Forest/Woodland	8048	12.6	5.8	47181	73.7	20.1	55229	86.3	14.8
Open Water	3177	5	2.3	1279	2.0	0.6	4456	7.0	1.2
Barren	183	0.3	0.1	14	0.02	0	197	0.3	0.1
Herbaceous	4616	7.2	3.3	ND	ND	ND	4616	7.2	1.2
Wetland	13888	21.7	10	ND	ND	ND	13888	21.7	3.7
Total	**138561**	**216.6**	**100**	**234375**	**366.2**	**100**	**372938**	**582.8**	**100**

Note: MoRAP = Missouri Resource Assessment Partnership
KARS = Kansas Applied Remote Sensing Program
ND = No Data. At the time of this TMDL, no data were available to estimate area of herbaceous and wetland land cover in Kansas.

In addition, approximately 8 percent of the watershed in Missouri is publicly owned. Out of 10,802 publicly-owned acres, 67 acres are managed by the Missouri Department of Natural Resources and the remainder is managed by the Missouri Department of Conservation (NRCS 2008).

2.5 Defining the Problem

A TMDL is needed for the Little Osage River because it is not meeting the water quality criterion for dissolved oxygen. Low dissolved oxygen is an issue because concentrations have been measured at less than the minimum water quality criterion of 5.0 mg/L.

Water from the Little Osage River was sampled and analyzed by the Department to produce water quality data of sufficient quality to evaluate compliance with water quality standards and to support TMDL development. In addition, water quality data recorded by the Kansas Department of Health and Environment, or KDHE, were used in evaluating compliance with water quality standards. The KDHE data, as well as continuous dissolved oxygen data from a 2007 biological assessment conducted by the Missouri Department of Natural Resources (MoDNR 2007), are summarized in Table 2 and indicate an 83.4 percent frequency of exceedance of the minimum dissolved oxygen criterion of 5 mg/L. All of the data from these surveys are presented in Appendix A.1.

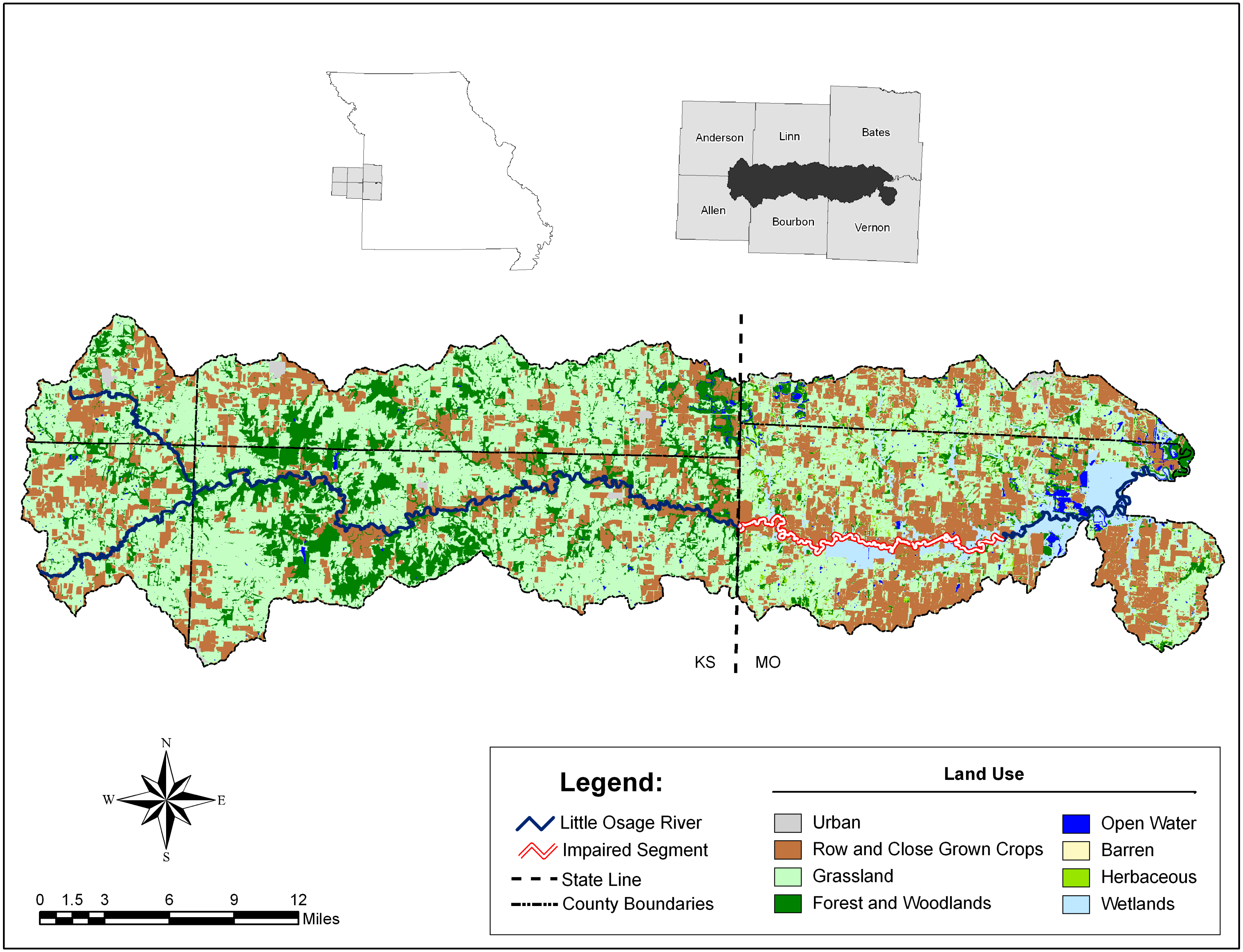

Figure 2. Land use/land cover in the Little Osage watershed (MoRAP 2005, KARS 2008)

Table 2. Summary of dissolved oxygen data for Little Osage River

Organization	Site Name	From	To	No. of samples	No. of samples <5 mg/L	Percent of samples <5 mg/L
KDHE	L. Osage@Fulton, KS	2000	2009	57	6	10.5
MoDNR	L. Osage@Hwy V, MO	7/25/06	7/28/06	299	291	97.3
Total				356	297	83.4

As discussed in Section 4, the low dissolved oxygen problem could be due to one or more of the following:

- Excessive loads of decaying organic solids, as measured by biochemical oxygen demand.
- Too much algae in the stream as a result of excessive phosphorus or nitrogen loading.
- High consumption of oxygen from decaying matter on the streambed, as measured by sediment oxygen demand.
- Physical factors associated with low reaeration rates.

3 Source Inventory

This section summarizes the available information on significant sources of nutrients and oxygen consuming substances in the Little Osage watershed. Point (or regulated) sources are presented first, followed by nonpoint (or unregulated) sources.

3.1 Point Sources

The term "point source" refers to any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel or conduit, by which pollutants are transported to a water body. Point sources are regulated through the Missouri State Operating Permit program, and include municipal wastewater treatment facilities[4]. By law, point sources also include: concentrated animal feeding operations (which are places where animals are confined and maintained or fed); storm water runoff from municipal separate storm sewer systems; and storm water runoff from construction and industrial sites. All of the permitted facilities in the Missouri portion of the Little Osage watershed are listed in Table 3 and shown in Figure 3.

Although there are four municipalities located within, or partially within, the Little Osage River watershed in Missouri, there are no municipal wastewater treatment facilities or municipal separate storm sewer systems that discharge into this part of the watershed. The two towns with wastewater treatment plants in Missouri, Hume and Rich Hill in Bates County, are both bisected by the northern boundary of the watershed and discharge to the north, into tributaries of the Marais des Cygnes River. The other two towns, Stotesbury and Metz, each with populations under one hundred people, do not have centralized municipal wastewater treatment.

There are four facilities with general permits, along with one general storm water permit, within the Little Osage watershed in Missouri. General and storm water permits (as opposed to site-

[4] The Missouri State Operating Permit program is Missouri's program for administering the federal National Pollutant Discharge Elimination System program.

specific permits) are issued to activities that are similar enough to be covered by a single set of requirements. Of these five facilities, two discharge to the downstream end of the impaired segment. One of these, a limestone quarry, is unlikely to be a source of nutrients or organic material that could be contributing to the dissolved oxygen impairment. The other, a fertilizer manufacturing facility, is authorized to discharge only storm water during high flow events. Given the location of this facility downstream of where the impairment was actually assessed, and the fact that critical conditions for low dissolved oxygen are considered during periods of low flow, it is unlikely that storm water discharge from this facility is a significant contributor to the low dissolved oxygen impairment. The other three facilities, a meat processing plant and two poultry concentrated animal feeding operations, are downstream of the impaired class C water body segment (see Figure 3 and Table 3). Their locations, along with the fact that they are all no-discharge facilities, would indicate that they are not contributing to the assessed low dissolved oxygen impairment that is being addressed in this TMDL.

While there are only two permitted concentrated animal feeding operations in the watershed (see Table 3), both are downstream of the impaired segment. As outlined in section 3.2, land use and agricultural statistics both indicate that livestock production is common in rural Bates and Vernon Counties. Animal feeding operations where animals are maintained or fed under confined conditions but which maintain fewer than 300 animal units are not legally defined as CAFOs under state regulations. Additionally, facilities that are defined as CAFOs but which maintain fewer than 1,000 animal units are not required to obtain a Missouri State Operating Permit. Since these operations are not regulated by the Department, there is no data available on their numbers or locations. Given the number of animals in both of these counties, it is possible that, along with grazing operations, there are unregulated animal feeding operations within the Little Osage River watershed. Unregulated operations that do not properly manage livestock waste may be potentially acting as point sources of nutrients and oxygen-consuming substances that contribute to the low dissolved oxygen impairment.

The portion of the Little Osage River watershed within the State of Kansas contains four permitted municipal wastewater dischargers. Each of these municipal facilities is a small, lagoon type system with individual design flows less than 40,000 gallons per day. Information regarding these municipal facilities, as well as two non-municipal permitted facilities located within Kansas, can be found in Table 4. Like Missouri, there are no municipal separate storm sewer systems in the Kansas portion of the watershed. In addition to the municipal and non-municipal systems, there are seven active livestock facilities within the Kansas portion of the watershed that are either certified or permitted by the State of Kansas. The total number of animal units[5] attributed to all of these facilities is 2,219. These livestock facilities are listed in Table 5 and are shown, along with the municipal and non-municipal wastewater treatment facilities, in Figure 3.

Illicit straight pipe discharges of household waste are also potential point sources in rural areas. These are discharges straight into streams or land areas and are different than illicitly connected sewers. There is no specific information on the number of illicit straight pipe discharges of household waste in the Little Osage watershed.

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[5] According to KSA 65-171d(c)(3), in Kansas one animal unit equals approximately 0.7 mature dairy cattle, 10 swine weighing 55 pounds or less, and 2.5 swine weighing greater than 55 pounds.

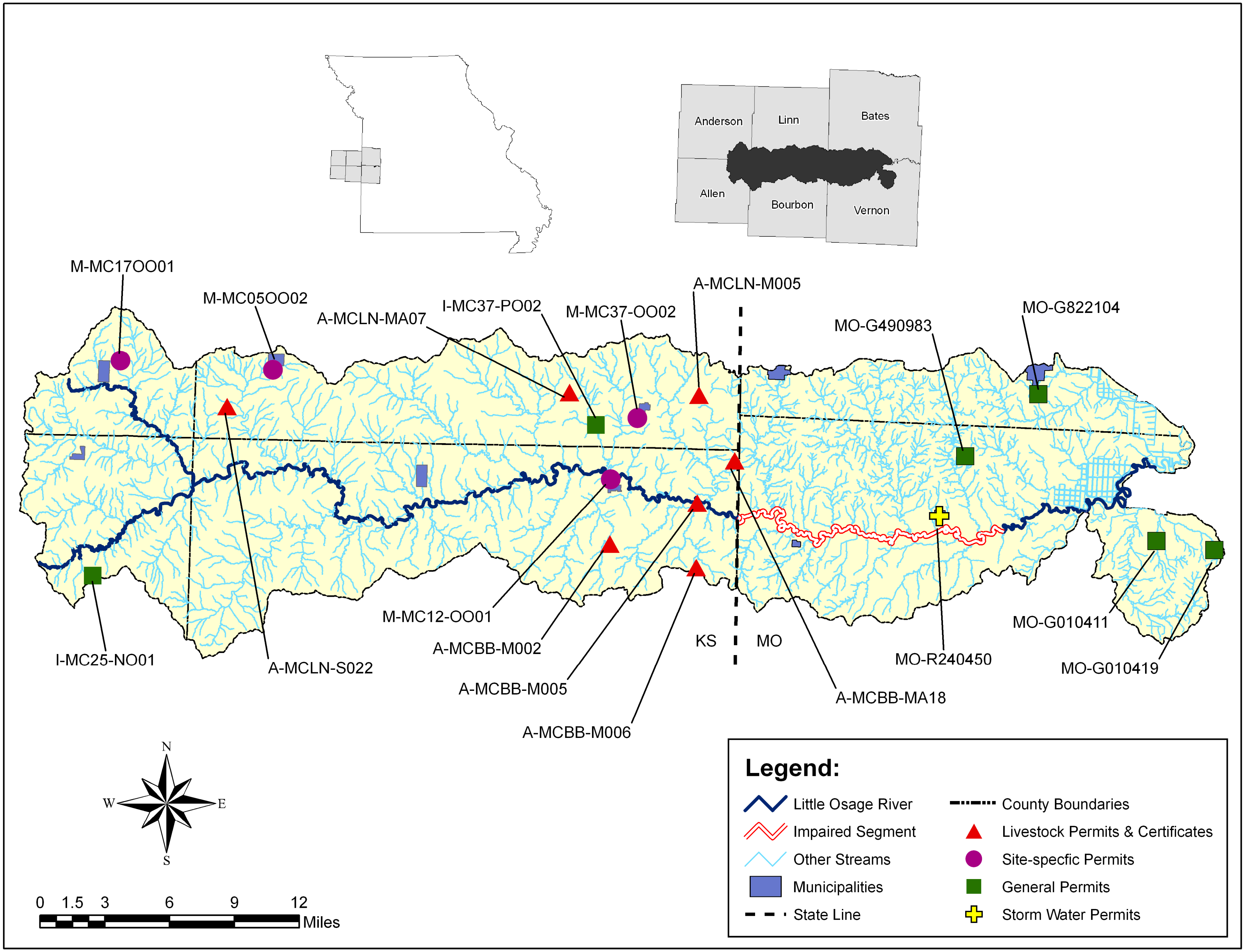

Figure 3. Location of permitted facilities in the Little Osage watershed

Table 3. Missouri permitted facilities in the Little Osage watershed

Facility ID	Facility Name	Receiving Stream	Permit Type	Permit Expiration Date
MO-G822104	Rich Hill Meat Processing	Tributary to Muddy Creek	General Permit	6/8/2011
MO-G490983	Rich Hill/Seagraves Quarry (Limestone)	Unnamed Tributary to Reed Creek	General Permit	10/5/2011
MO-G010411	Paul Leatherman (Poultry CAFO)	Bee Branch	General Permit	2/23/2011
MO-G010419	Steven Schmidt (Poultry CAFO)	E. Fork Bee Branch	General Permit	2/23/2011
MO-R240450	Midwest Fertilizer, Inc.	Unnamed Tributary to Little Osage	Storm water Permit	2/19/14

Note: CAFO = Concentrated Animal Feeding Operation

Table 4. Kansas permitted facilities in the Little Osage watershed

Kansas Facility ID	NPDES ID	Facility Name	Receiving Stream	Design Flow (MGD)	Permit Expiration Date	Pollutant contribution[6]		
						TN lbs/day	TP lbs/day	TSS T/day
MMC05OO02	KS0095737	Blue Mound WWTP	Irish Creek	0.03	9/30/2014	0.21	0.02	0.002
MMC12OO01	KS0081701	Fulton WWTP	Little Osage River	0.025	9/30/2014	0.18	0.02	0.002
MMC17OO01	KS0080578	Kincaid WWTP	Unnamed Trib. to N. Fork Little Osage River	0.03	6/30/2014	0.21	0.02	0.002
MMC37OO02	KS0095508	Prescott WWTP	E. Laberdie Creek	0.04	9/30/2014	0.29	0.03	0.003
I-MC25-NO01	KSJ000499	Stewart Manufacturing Corp.	S. Fork Little Osage River	No discharge	Inactive	NA		
I-MC37-PO02	KS0092797	Continental Coal - Lost Creek Mine	Elk Creek	No discharge	Inactive	NA		

Note: WWTP = Wastewater treatment plant

[6] This represents the potential contribution of nutrients and TSS based on facility design flow and reference concentration targets of 0.855 mg/L, 0.092 mg/L and 16.75 mg/L for TN, TP and TSS, respectively (see Section 5.3 for discussion of these targets).

Table 5. Kansas livestock facilities in the Little Osage watershed.

Active Livestock Permits		
Permit Number	**Type**	**Animal Units**[7]
A-MCLN-S022	Swine	988
A-MCLN-M005	Dairy	355
A-MCBB-M002	Dairy	287
A-MCBB-M005	Dairy	143
A-MCBB-M006	Dairy	250
A-MCBB-L007*	Goat	33
A-MCBB-L008*	Goat	98
Active Livestock Certificates		
Certificate Number	**Type**	**Animal Units**
A-MCLN-MA07	Dairy	140
A-MCBB-MA18	Dairy	56

*Location information for these permits not available at time of TMDL submittal.

3.2 Nonpoint Sources

Nonpoint sources include all other categories not classified as point sources. Potential nonpoint sources contributing to low dissolved oxygen problems in the Little Osage watershed include runoff from agricultural areas, runoff from urban areas, onsite wastewater treatment systems, and various sources associated with riparian habitat conditions. Each of these is discussed further in the following sections.

3.2.1 Runoff from Agricultural Areas

The 2005 land use/land cover data indicate there are nearly 100,000 acres of cropland in the Little Osage watershed, with roughly equivalent areas in both Kansas and Missouri (see Table 1) (MoRAP 2005 and KARS 2008). Lands used for agricultural purposes can be a source of nutrients and oxygen-consuming substances in the river. Accumulation of nitrogen and phosphorus on cropland occurs primarily from decomposition of residual crop material and fertilization with chemical and manure fertilizers. Nutrients and organic materials from crop fields are transported to adjacent streams during precipitation events through the processes of surface runoff and soil erosion. These processes can be compounded by tilling of farm fields and by applying fertilizers prior to precipitation events or at rates exceeding the assimilative capacity of the soil. As noted in Section 2.3, roughly 88 percent of the soils in the Little Osage watershed in Missouri have low infiltration rates and roughly 22 percent of the land area is considered

[7] As defined in Kansas statute KSA 65-171d(c)(3).

highly or potentially highly erodible. In Kansas, 98 percent of the watershed produces runoff under relatively low infiltration potential conditions.

Countywide data from the National Agricultural Statistics Service (USDA 2009a) were combined with the land cover data for the Little Osage watershed to estimate there are approximately 16,935 cattle in the Missouri portion of the watershed[8]. Livestock specialists in Bates and Vernon Counties have confirmed that the majority of the cattle being raised in this area are in cow/calf grazing operations[9]. These cattle are therefore most likely located on the approximately 57,570 acres of grassland/pastureland in the Missouri side of the watershed and runoff from these areas can also be a potential source of nutrients and oxygen consuming substances. For example, animals grazing in pasture areas deposit manure directly upon the land surface and, even though a pasture may be relatively large and animal densities low, the manure will often be concentrated near the feeding and watering areas in the field. These areas can quickly become barren of plant cover and increase the possibility of erosion and contaminated runoff during a storm event. When pasture land is not fenced off from the stream, cattle or other livestock may contribute nutrients directly to the stream while walking in or adjacent to the water body.

When considering the potential impacts of crop production and livestock grazing in the Little Osage River watershed, it is worth noting that pecans are a major crop in Vernon County. Vernon County is home to 30 percent of all pecan farms in the state, and roughly 71 percent of all acreage devoted to growing pecans. This is significant because pecan trees in Missouri require deep, well drained soils with adequate moisture, and are largely grown in the floodplains of major rivers (Reid 2000). Given the concentration of orchards in the vicinity, it is reasonable to assume that some are located in the wide alluvial valleys of the Little Osage River. In additon to requiring fertilization, pecan orchards can also be subject to livestock grazing, a management strategy designed to minimize ground cover. Both practices can be sources of nutrients to the Little Osage River, particularly during periods of flooding.

An additional potential source of nutrients from agricultural lands may come from the application of poultry manure to cropland and livestock pastures. Under the right conditions, land application serves both as an inexpensive method for disposing of waste from large-scale poultry producing operations and as a readily available fertilizer to improve the growth of crops and forage. However, as noted above, too much manure applied at the wrong times can result in excess nutrients and organic matter reaching nearby streams. While poultry production in Missouri is concentrated in the southwest region of the state, waste generated from these facilities is land applied as far north as Vernon County (Darrick Steen, Missouri Department of Natural Resources, personal communication, August 21, 2009). Although data identifying

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[8] According to the National Agricultural Statistics Service, there are an estimated 149,000 head of cattle in Vernon and Bates Counties (USDA, 2007). According to the 2005 Land Use Land Cover data from the Missouri Resource Assessment Partnership there are 791.5 square miles of grasslands in Vernon and Bates Counties (MoRAP, 2005). These two values result in a cattle density of approximately 188 cattle per square mile of grassland. This density was multiplied by the number of square miles of grassland in the Little Osage watershed to estimate the number of cattle in the watershed.

[9] Al Decker, Livestock Specialist, University of Missouri Extension Service, Bates and Vernon Counties; and Brad Powell, District Technician, USDA Natural Resources Conservation Service, Bates County; personal communications, February 1, 2010.

exactly where this litter is spread is not available, anecdotal reports suggest that at least some may be applied to land within the Little Osage River watershed (Mark Curtis, District Manager, USDA Natural Resources Conservation Service, personal communication, February 2, 2010). Another potential source of poultry litter may be the two poultry operations located downstream in the watershed.

Based on information generated for previous TMDL projects, the density of cattle in the Little Osage watershed within Missouri may potentially be a significant source of pollutants to the impaired segment (OEPA 2007; Tetra Tech 2009). The relative impact of a cattle density of 78 cattle per square mile becomes significant when compared to a human population density of 13 persons per square mile. Likewise, the density of 188 head of cattle per square mile of grassland (Footnote 5) takes on additional importance when grassland comprises roughly 41 percent of the riparian area in the entire watershed.

Employing a similar analysis using agricultural and land use data from Kansas, it is estimated there are roughly 25,694 cattle in the Kansas portion of the Little Osage watershed. This results in a livestock density of 70 cattle per square mile (KARS 2008 and USDA 2009a). It should be noted this estimated density is variable and dependent upon the locations of the permitted concentrated feeding operations in the Kansas portion of the watershed.

The National Agricultural Statistics Service also reports there were at least 338,569 hogs and pigs, 2,419 sheep and lambs, and 3,682 poultry layers in Bates and Vernon Counties, Missouri in 2007. In addition, there were at least 6,363 hogs and pigs, 841 sheep and lambs, and 3,460 poultry layers in the four counties in Kansas that the Little Osage River flows through. No data are available to estimate the number of these other livestock that might be located in the Little Osage watershed (USDA 2009a).

3.2.2 Runoff from Urban Areas

Storm water runoff from urban areas can also be a significant source of nutrients and oxygen consuming substances. In fact, phosphorus loads from residential areas can be comparable to or higher than loading rates from agricultural areas (Reckhow *et al.* 1980; Athayde *et al.* 1983). In addition, storm water runoff from parking lots and buildings is warmer than runoff from grassy and woodland areas. This difference in surface runoff temperature can lead to higher instream water temperatures that lower the dissolved oxygen saturation capacity of the stream. Excessive discharge of suspended solids from urban areas can also lead to streambed siltation problems. Furthermore, leaking or illicitly connected sewers can also be a significant source of pollutant loads within urban areas.

Approximately 4.4 square miles (0.7 percent) of the Little Osage River watershed is classified as urban and 70 percent of the urban land use is within Missouri. Only two small towns in Missouri – Stotesbury and Metz – are adjacent to the impaired segment and, as previously noted, each has a population under one hundred people. Given the small size of the urban landscape in the watershed, it is unlikely that urban storm water runoff is a significant source of the substances and conditions affecting dissolved oxygen.

3.2.3 Onsite Wastewater Treatment Systems

Onsite wastewater treatment systems (e.g., septic systems) that are properly designed and maintained should not serve as a source of contamination to surface waters. However, onsite wastewater treatment systems do fail for a variety of reasons. When these systems fail hydraulically (surface breakouts) or hydrogeologically (inadequate soil filtration) there can be adverse effects to surface waters (Horsely and Witten 1996). Failing septic systems are sources of nutrients that can reach nearby streams through both surface runoff and groundwater flows.

The exact number of onsite wastewater systems in the Little Osage watershed is unknown. However, as discussed in Section 2.2, the estimated rural population of the Little Osage watershed is approximately 4,374 persons with an estimated rural population in the Missouri portion of 1,760 persons[10] (U.S. Census Bureau 2000). Based on this population, and an average density of 2.5 persons per household, there may be approximately 1,750 systems in the entire watershed with 704 of those in Missouri.

No precise information exists on the failure rate of onsite wastewater treatment systems within the Little Osage watershed. The only available information comes from complaints that are received by the Bates and Vernon County Health Departments which have regulatory authority over onsite wastewater systems. It is estimated that Bates County and Vernon County receive about 10 complaints and 30 complaints per year, respectively, regarding onsite wastewater treatment systems. Of these complaints, there are perhaps only eight violations each year involving onsite wastewater systems in the vicinity of the Little Osage watershed (Steve Durnell, Inspector with Vernon and Bates County Health Departments, personal communication, August 24, 2009). Overall, EPA reports that the statewide failure rate of onsite wastewater systems in Missouri is 30 to 50 percent (EPA 2002).

3.2.4 Riparian Habitat Conditions

Riparian habitat[11] conditions can also have a strong influence on instream dissolved oxygen. Wooded riparian buffers are a vital functional component of stream ecosystems and are instrumental in the detention, removal, and assimilation of nutrients before they reach surface water. Therefore, a stream with good riparian habitat is generally better able to moderate the impacts of high nutrient loads than a stream with poor habitat. Wooded riparian corridors can also help by providing shading that reduces stream temperatures and cooler stream temperatures can result in increased dissolved oxygen saturation capacity of the stream.

Riparian areas can also be sources of natural background material that could possibly contribute to the low dissolved oxygen problem. While riparian areas that are wooded and have a diversity of natural vegetation can help mitigate conditions that cause low dissolved oxygen, leaf fall from vegetation near the water's edge, aquatic plants, and drainage from organically rich areas like wetlands are all natural sources of materials that consume oxygen.

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[10] The total watershed population minus the population of all urban areas.
[11] A riparian corridor (or zone or area) is the linear strip of land running adjacent to a stream bank.

Also, as indicated in Table 6, roughly 41 percent of the land in the riparian corridor adjacent to the Little Osage River and its tributaries is classified as grassland. Non-native grassland provides limited riparian habitat and very little shading compared to wooded areas and, as previously mentioned, can be subject to erosion and nutrient loading associated with livestock activity. Another 14 percent of the riparian area is classified as cropland which, like grassland, provides limited riparian habitat compared to wooded areas and leaves these areas more susceptible to soil erosion and high nutrient concentrations. In the Missouri portion of the watershed, cropland accounts for over 22 percent of the riparian area, which is consistent with the overall higher proportion of that land use in this portion of the watershed. Indeed, a visual survey of the land use map appears to show a pattern of cropland that lies within the relatively wide, flat alluvial valleys of the main stem of the Little Osage and its major tributaries. Although the Department does not have data to indicate how pecan orchards are classified in the land use and land cover data, as noted in Section 3.2.1 pecan cultivation is common in the floodplains of this region, and may also be a source of nutrients to the Little Osage River.

Efforts to improve riparian habitat conditions should therefore be an important component of the implementation of the TMDL.

Table 6. Percentage of land cover within the Little Osage River riparian corridor 30-meter (MoRAP 2005, KARS 2008).

Land Use/Land Cover	Missouri	Kansas	Missouri & Kansas
Urban	0.5	0.2	0.4
Barren	0.1	0	0.03
Cropland	22.3	7.6	14.3
Grassland	39.4	42.3	41
Forest & Woodland	8.5	48.3	30.1
Herbaceous	5.0	ND	2.3
Wetland	19.8	ND	9.1
Open Water	4.4	1.6	2.9

Note MoRAP = Missouri Resource Assessment Partnership
KARS = Kansas Applied Remote Sensing Program
ND = No Data. At the time of this TMDL, no data were available to estimate area of herbaceous and wetland land cover in Kansas.

4 Applicable Water Quality Standards and Numeric Water Quality Targets

The purpose of developing a TMDL is to identify the pollutant loading that a water body can receive and still achieve water quality standards. Water quality standards are therefore central to the TMDL development process. Under the federal Clean Water Act, every state must adopt water quality standards to protect, maintain, and improve the quality of the nation's surface waters (U.S Code Title 33, Chapter 26, Subchapter III (U.S. Code 2009)). Water quality standards consist of three components: designated beneficial uses, water quality criteria to protect those uses, and an antidegradation policy.

4.1 Designated Beneficial Uses

The designated beneficial uses of the Little Osage River, WBID 3652, are:

- Livestock and Wildlife Watering.
- Protection of Warm Water Aquatic Life.
- Protection of Human Health (Fish Consumption).
- Whole Body Contact Recreation – Category B.

The use that is impaired is Protection of Warm Water Aquatic Life. The designated uses and stream classifications for Missouri may be found in the Water Quality Standards at 10 CSR 20-7.031(1)(C),-(1)(F) and Table H (Missouri Secretary of State 2008).

4.2 Numeric Criteria

This section presents Missouri's numeric criteria for dissolved oxygen and also provides a brief description of why dissolved oxygen is important to water quality, how it is measured, and how it is related to other water quality parameters.

Dissolved oxygen is one of the most critical characteristics of our surface waters because fish, mussels, macroinvertebrates, and most other aquatic life utilize dissolved oxygen in the water to survive. The water quality criterion for dissolved oxygen for all Missouri streams except cold water fisheries is a daily minimum of 5 milligrams per liter (mg/L) (10 CSR 20-7.031 Table A; Missouri Secretary of State 2008).

Dissolved oxygen in streams is affected by several factors including water temperature, the amount of decaying organic matter in the stream, turbulence at the air-water interface and the amount of photosynthesis occurring in plants within the stream. Organic matter can come from wastewater effluent as well as agricultural and urban runoff. The rate at which organic matter decays and consumes oxygen is often measured instream as biochemical oxygen demand, or BOD.

Organic matter can also accumulate on the bottom of streams, where the rate at which it decays and consumes oxygen is measured as sediment oxygen demand, or SOD. Sediment oxygen demand is a combination of all of the oxygen-consuming processes that occur at or just below the sediment/water interface. The processes that occur within this area of the stream bed can account for a large fraction of the oxygen consumption in a stream. Most of the sediment oxygen demand at the surface of the sediment is due to the biological decomposition of organic material and the bacterially facilitated nitrification of ammonia, while the sediment oxygen demand several centimeters into the sediment is often dominated by the chemical oxidation of species such as iron, manganese, and sulfide (Wang 1980; Walker and Snodgrass 1986). Sediment oxygen demand can also be affected by water depth, current velocity, and temperature.

Nitrogen and phosphorus can also contribute to low dissolved oxygen problems because they can accelerate algae growth in streams. Algae growth in streams is most frequently assessed based on the amount of chlorophyll *a* in the water. The algae consume dissolved oxygen during

respiration and have the potential to remove large amounts of dissolved oxygen from the stream, particularly at night when dissolved oxygen is not produced through photosynthesis. The breakdown of dead, decaying algae also removes oxygen from water. The dissolved oxygen, biochemical oxygen demand, nitrogen, and phosphorus data for the Little Osage River are summarized in Table 8 of Section 5.

4.3 Antidegradation Policy

Missouri's water quality standards include EPA's "three-tiered" approach to antidegradation, which may be found at 10 CSR 20-7.031(2) (Missouri Secretary of State 2008).

> Tier 1 – Protects existing uses and a level of water quality necessary to maintain and protect those uses. Tier 1 provides the absolute floor of water quality for all waters of the United States. Existing instream water uses are those uses that were attained on or after November 28, 1975, the date of EPA's first Water Quality Standards Regulation.
>
> Tier 2 – Protects and maintains the existing level of water quality where it is better than applicable water quality criteria. Before water quality in Tier 2 waters can be lowered, there must be an antidegradation review consisting of: (1) a finding that it is necessary to accommodate important economical and social development in the area where the waters are located; (2) full satisfaction of all intergovernmental coordination and public participation provisions; and (3) assurance that the highest statutory and regulatory requirements for point sources and best management practices for nonpoint sources are achieved. Furthermore, water quality may not be lowered to less than the level necessary to fully protect the "fishable/swimmable" uses and other existing or designated uses.
>
> Tier 3 – Protects the quality of outstanding national and state resource waters, such as waters of national and state parks, wildlife refuges, and exceptional recreational or ecological significance. There may be no new or increased discharges to these waters and no new or increased discharges to tributaries of these waters that would result in lower water quality.

Waters in which a pollutant is at, near or exceeds the water quality criteria are considered in Tier 1 status for that pollutant. Therefore, the antidegradation goal for Little Osage River is to restore the stream's dissolved oxygen level to the water quality standards.

5 TMDL Development

5.1 Data Collection

To fully understand the cause of the low dissolved oxygen problem, EPA Region 7 collected water quality data in the spring (April 21-24) and summer (August 25-28) of 2008 from the Little Osage River. Continuous water quality data were measured using data loggers deployed at three sites along the river and grab samples were taken on deployment and removal of the data

loggers. The location of the sampling sites are provided in Figure 4. The diurnal dissolved oxygen curves for the three sites for the summer of 2008 are presented in Figure 5, and the corresponding water quality data from the grab samples can be found in Table 8. The continuous water quality data, together with the water chemistry information derived from the grab samples, were used in the development of a steady-state water quality model for the Little Osage River. The model was developed to characterize the diurnal fluctuation of dissolved oxygen and to serve as a basis for developing the TMDL for the impaired segment.

Both the diurnal dissolved oxygen data represented in Figure 5, and the dissolved oxygen data from the grab samples presented in Table 8, appear to indicate that dissolved oxygen levels at Site 3 more frequently violate the 5 mg/L minimum water quality criterion. This is consistent with historical data at this site (Little Osage River at Highway V). Data presented in Appendix A.1 from 2000-2009 shows that dissolved oxygen fell below 5 mg/L for 11 out of 12 sampling events at this site for which there is dissolved oxygen data.

5.2 Diurnal Dissolved Oxygen Analysis

The continuous dissolved oxygen data were analyzed using a single-station diurnal curve analysis model (Odum 1956 and Kosinski 1984). The single-station method allows the determination of the relative magnitudes of stream reaeration, total community respiration, and gross and net primary production.

The Kansas Biological Survey, or KBS (Anderson and Huggins 2003), developed a spreadsheet model based on the single-station method. The KBS spreadsheet determines instream values for respiration, gross productivity, and net productivity and was used as the basis for the Little Osage River modeling study. Because the KBS spreadsheet model requires an independent estimate of stream reaeration, reaeration rates for the Little Osage River were estimated using the surface renewal method of O'Connor and Dobbins (1956). Considering the estimated depths and velocities of the river observed during the sampling events of summer 2008, the O'Connor and Dobbins equation is an appropriate means of determining an estimate of stream reaeration, as indicated in Table 7 (Wilcock 1988).

Table 7. Suggested rearation equations for flow depths and velocities (Wilcock 1982 as cited by Anderson and Huggins 2003).

Velocity, U (m/s)	Depth, z (m)			
	0.25 – 0.50	0.50 – 1.0	1.0 – 3.0	3.0 – 6.5
0.1 – 0.3	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins
0.3 – 0.5	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins	O'Connor-Dobbins
0.5 – 1.0	Negulescu-Rojanski	Isaacs-Gaudy	Chuchill-Elmore-Buckingham	Chuchill-Elmore-Buckingham
1.0 – 2.0	Negulescu-Rojanski	Isaacs-Gaudy	Chuchill-Elmore-Buckingham	Chuchill-Elmore-Buckingham

The summary of the single-station dissolved oxygen analysis is presented in Table 9. The table shows that the estimate of total community respiration exceeds the gross primary production for all the sites during the summer sampling period. Total community respiration exceeding gross primary production resulted in a negative net production. Results of the single-station dissolved oxygen diurnal curve analysis were used to guide the parameterization of the water quality model for Little Osage River.

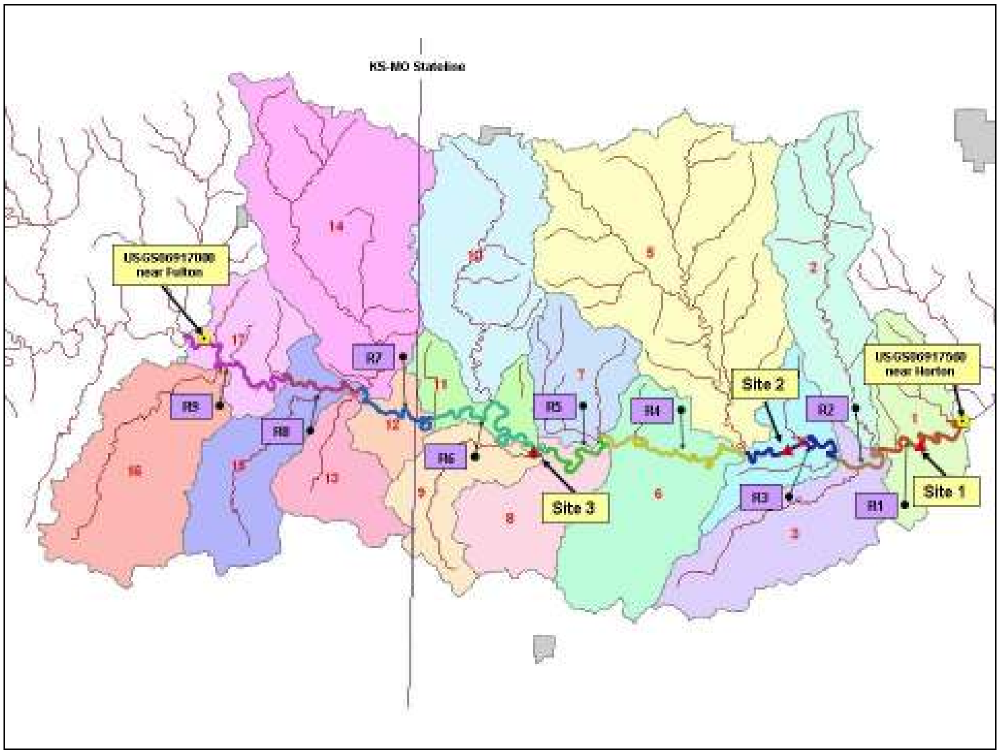

Figure 4. Location of Little Osage sampling sites and schematic of model domain. The data loggers were deployed at all three sites.

Table 8. EPA water quality data for the Little Osage River.

Site	Date	Time	Temp deg C	KSP uS/cm	DO mg/L	pH	Alk mg/L	BOD_5 mg/L	CHLa ug/L	NH3-N ug/L	TKN ug/L
Little Osage 1	4/21/2008	14:44	15.7	385	7.7	8.1	160	2.0	5.4	100	727
Little Osage 1	4/24/2008	13:56	17.2	240	8.4	7.2	92	7.2	14.6	100	4370
Little Osage 1	8/25/2008	13:30	25.2	424	4.95	7.5	151	2.0		100	908
Little Osage 1	8/28/2008	12:45	25.5	324	5.02	7.5	156	2.2		125	1050
Little Osage 2	4/21/2008	13:53	16	377	8.2	8.1	157	2.0	4.3	100	1020
Little Osage 2	4/24/2008	13:10	17.5	304	7.5	6.8	104	5.4	16.7	100	3640
Little Osage 2	8/25/2008	12:45	23.5	503	4.7	7.4	151	2.0		100	912
Little Osage 2	8/28/2008	12:15	24.8	541	4.15	7.4	156	2.0		100	942
Little Osage 3	4/21/2008	12:49	15.4	378	7.7	7.7	160	2.0	4.2	100	1240
Little Osage 3	4/24/2008	12:13	16.9	198	6.9	7.9	86.6	5.6	12.1	100	4470
Little Osage 3	8/25/2008	11:30	23.6	590	3.39	7.4	156	2.1		112	928
Little Osage 3	8/28/2008	11:15	24	637	3.53	7.4	161	2.0		100	960

Table 8 (cont). EPA water quality data for the Little Osage River

Site	Date	Time	NO23-N ug/L	TP ug/L	dOP-P ug/L	TSS mg/L	TOC mg/L	NVSS mg/L	VSS mg/L	Turb ntu	SS ml/l/hr
Little Osage 1	4/21/2008	14:44	562	373	34	48	4.4	2.5	45.5	125	1.0
Little Osage 1	4/24/2008	13:56	736	4760	105	1300	24.4	919.1	380.9	960	1.2
Little Osage 1	8/25/2008	13:30	175	1230	25	19	6.2	10.4	8.6	96	1.0
Little Osage 1	8/28/2008	12:45	92	1870	42	15.8	7.8	12.4	3.4	88	1.0
Little Osage 2	4/21/2008	13:53	542	303	37	67	5.3	27.8	39.2	103	1.0
Little Osage 2	4/24/2008	13:10	868	4190	96	1100	18.7	799.7	300.3	788	1.3
Little Osage 2	8/25/2008	12:45	183	894	22	22.1	6.0	13.6	8.5	66	1.0
Little Osage 2	8/28/2008	12:15	135	1280	44	48	8.3	33.9	14.1	104	1.0
Little Osage 3	4/21/2008	12:49	501	380	33	71	4.8	35.1	35.9	88	1.0
Little Osage 3	4/24/2008	12:13	628	3810	57	1200	19.9	859.2	340.8	999	1.0
Little Osage 3	8/25/2008	11:30	226	1255	22	33	6.0	26.1	6.9	90	1.0
Little Osage 3	8/28/2008	11:15	162	1060	30	50.6	6.7	37.3	13.3	82	1.0

Note: SS = Settlable solids

Table 9. Estimates of gross productivity, net productivity, and respiration for the Little Osage River August 25 – 28.

Little Osage River	Reaeration $k_{2,20}$ 1/day	Net Production $gO^2/m^2/day$	Respiration $gO^2/m^2/day$	Gross Production $g\ O^2/m^2/day$
Site 1	4.15	-5.76	6.45	0.68
Site 2	6.28	-8.61	9.15	0.54
Site 3	7.11	-10.69	11.35	0.66

Note: $k_{2,20}$ 1/day = Rearation constant at 20° celsius per day.
$gO^2/m^2/day$ = grams of oxygen per square meter per day.

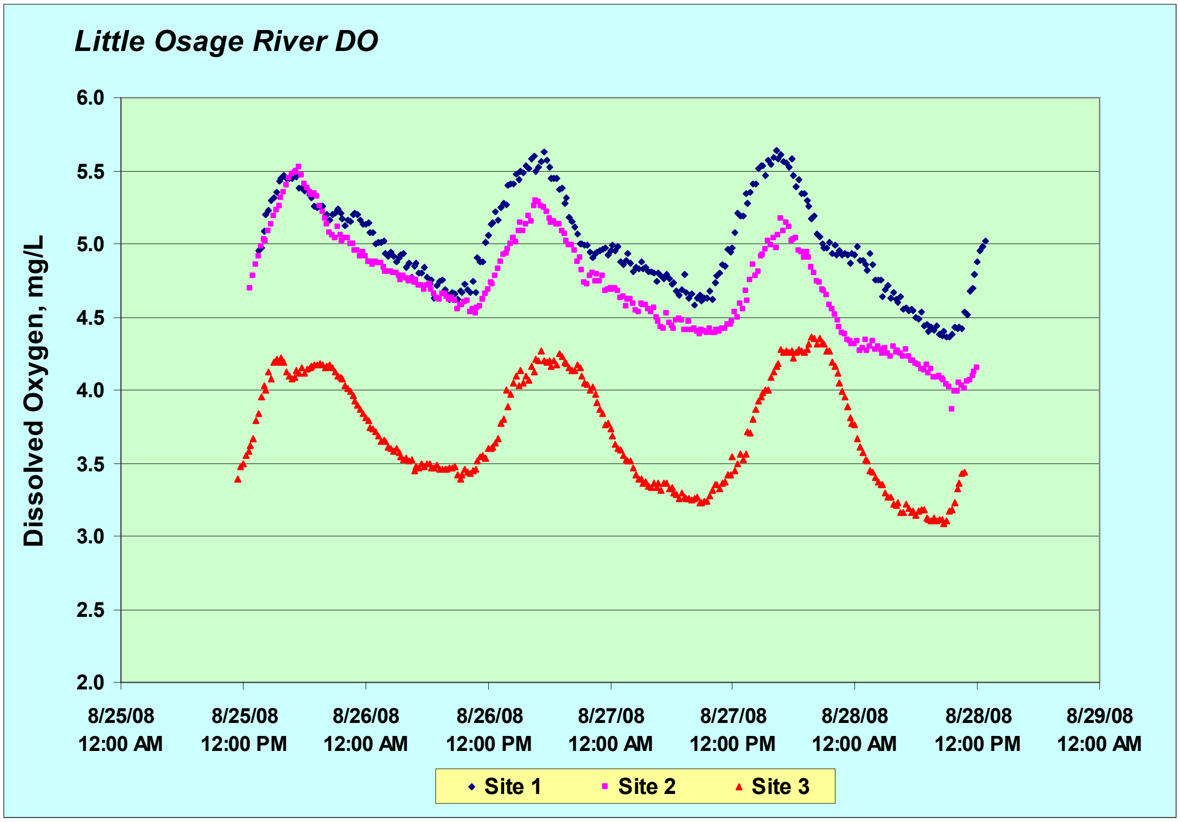

Figure 5. Continuous dissolved oxygen data for three sites on the Little Osage River.

5.3 TMDL Modeling[12]

Dissolved oxygen in streams is determined by the factors of photosynthetic productivity, respiration (autotrophic and heterotrophic), reaeration, and temperature. These factors are influenced by natural and anthropogenic conditions within a watershed. Generally, reaeration is based on the physical properties of the stream and on the capacity of water to hold dissolved oxygen. This capacity is mainly determined by water temperature, with colder water having a higher saturation concentration for dissolved oxygen. In a review of variables and their importance in dissolved oxygen modeling, Nijboer and Verdonschot (2004) categorized the impact of a number of variables on oxygen depletion. For this TMDL, the effects of temperature and the physical aspects of the stream itself were discounted. Even though the hydrological regime of historic prairie streams was modified by changes in land cover and channelization, manipulation of these parameters does not address a pollutant and so is not the goal of a TMDL. Pollutants which result in oxygen concentrations below saturation are:

- fine particle size of bottom sediment
- high nutrient levels (nitrogen and phosphorus)
- suspended particles of organic matter

[12] EPA Region 7 performed the modeling for this TMDL

Because these three variables vary to a large extent based on anthropogenic influences, they are appropriate targets for a TMDL written to address an impairment of low dissolved oxygen.

Since fine particle sized sediment and suspended particles of organic matter are derived from similar loading conditions of terrestrial and stream bank erosion, the Little Osage River TMDL will have as one of its allocations total suspended solids (see Appendix B for discussion of development of total suspended solids targets). The total suspended solids target was derived based on a reference condition approach by targeting the 25th percentile of total suspended solids measurements collected by the U.S. Geological Survey, or USGS, in the geographic region in which the Little Osage River is located (see Appendix A.2 for a list of sites and data). The calculated reference concentration target for total suspended solids is 16.75 mg/L. To address nutrient levels of total nitrogen and phosphorous, the EPA nutrient ecoregion reference concentrations were used. For the ecoregion where the Little Osage River is located, the reference concentration for total nitrogen[13] is 0.855 mg/L and the reference concentration for total phosphorus is 0.092 mg/L (EPA 2001a and EPA 2001b). This TMDL will not specifically target chlorophyll *a* as a wasteload allocation, but will use a linkage between nutrient concentrations and chlorophyll response to achieve the ecoregion reference concentrations.

5.3.1 Load Duration Curves

To develop load duration curves for total nitrogen and total phosphorus, a method similar to that used for total suspended solids was employed. First, total nitrogen and total phosphorus measurements were collected from USGS sites in the vicinity of the impaired stream segment. These data were adjusted such that the median of the measured data was equal to the ecoregion reference concentration. This was accomplished by subtracting the difference of the data median and the reference concentration. Where this would result in a negative concentration, the data point in question was replaced with the minimum concentration seen in the measured data. This resulted in a modeled data set which retained much of the original variability seen in the measured data. This modeled data was then regressed as instantaneous load versus flow. The resultant regression equation was used to develop the load duration curve.

To develop the TMDL expression of maximum daily loads, the background discharge at the stream outlet was modified from the traditional approach using synthetic flow estimation. Because there are no permitted facilities with designated design flows that discharge to the impaired segment, the TMDL curves in the load duration curves are not affected by point source discharges.

5.3.2 QUAL2K

An essential component of developing a TMDL is establishing a relationship between the source loadings and the resulting water quality. For this TMDL, the relationship between the source loadings of sediment oxygen demand and nutrients on dissolved oxygen is generated by the water quality model QUAL2K (Chapra et al. 2007).

---

[13] Total Kjeldahl nitrogen and nitrate plus nitrite as nitrogen

QUAL2K is supported by EPA and it and its predecessor (QUAL2E) have been used extensively for TMDL development and point source permitting issues across the country, especially for dissolved oxygen studies. QUAL2K is well accepted within the scientific community because of its proven ability to simulate the processes important to dissolved oxygen conditions within streams. The QUAL2K model is suitable for simulating the hydraulics and water quality conditions of a small river. It is a one-dimensional model with the assumption of a completely mixed system for each computational cell. QUAL2K assumes that the major pollutant transport mechanisms, advection and dispersion, are significant only along the longitudinal direction of flow. The model allows for multiple waste discharges, water withdrawals, tributary flows, and incremental inflows and outflows. The processes employed in QUAL2K address nutrient cycles, algal growth, and dissolved oxygen dynamics.

A QUAL2K model was developed for the Little Osage River. The model was calibrated for the flow and water quality data measured on August 27, 2008. The results of the model indicate that an 82 percent reduction in sediment oxygen demand is required to meet the dissolved oxygen criterion of 5.0 mg/L throughout the Missouri portion of the Little Osage River. Reductions in total suspended solids (organic matter) and nutrients are recommended in order to reduce sediment oxygen demand. A discussion of the TMDL allocations needed to achieve this 82 percent reduction is included in the following sections and a more detailed discussion of the QUAL2K model is included in Appendix C.

6 Calculation of Load Capacity

Load capacity, or LC, is defined as the greatest amount of loading of a pollutant that a water body can receive without violating water quality standards. This load is then divided among the sum of the point source (wasteload allocation, or WLA) and nonpoint source (load allocation, or LA) contributions to the stream with an allowance for an explicit margin of safety, or MOS. If the margin of safety is implicit, no numeric allowance is necessary. The load capacity of the stream can therefore be expressed in the following manner:

$$LC = \sum WLA + \sum LA + MOS$$

The wasteload allocation and load allocation are calculated by multiplying the appropriate stream flow in cubic feet per second, or cfs, by the appropriate pollutant concentration in mg/l. A conversion factor of 5.395 is used to convert the units (cfs and mg/L) to pounds per day (lbs/day).

(stream flow in cfs)(maximum allowable pollutant concentration in mg/L)(5.395)= pounds/day

Critical conditions must be considered when the load capacity is calculated. Dissolved oxygen levels that threaten the integrity of aquatic communities generally occur during low flow periods, so these periods are considered the critical conditions for the purpose of the dissolved oxygen model (QUAL2K).

7 Wasteload Allocation (Point Source Load)

The wasteload allocation is the portion of the load capacity that is allocated to existing or future point sources of pollution. At the present time, there are no non-storm water dischargers with site-specific Missouri State Operating Permits that have an established design flow in the Little Osage watershed. Therefore, no portion of the TMDL load capacity will be allocated to point sources and wasteload allocations are set at zero.

8 Load Allocation (Nonpoint Source Load)

The load allocation includes all existing and future nonpoint sources and natural background contributions of pollutants (40 CFR § 130.2(g)). The load allocations for the Little Osage River TMDL are for all nonpoint sources of total phosphorus, total nitrogen and total suspended solids. These can include loads from agricultural lands, including cultivated cropland and grassland utilized for livestock grazing, runoff from urban areas, animal feeding operations, and failing onsite wastewater treatment systems. The load allocations provided were calculated based on the total of all headwater and lateral inflow loads used in the QUAL2K model for the allocation scenario model run. The load allocations are intended to allow the dissolved oxygen target to be met at all locations within the stream under a variety of flow conditions.

The load duration curves for the targeted pollutants are depicted in Figures 6 through 8, where the TMDL curve represents the total load capacity of the pollutant for the entire Little Osage watershed upstream of the Marmaton River. The curves represent conditions ranging from the highest possible flow (flow exceeded 0 percent of the time) to the lowest flow (flow exceeded 100 percent of the time). Because no point sources exist in the watershed to receive wasteload allocations, the total load capacity is allocated to nonpoint sources as load allocations.

TMDL load capacities and load allocations for the targeted pollutants of concern are outlined in Tables 10 through 15 for a range of flow conditions. Tables 10, 12 and 14 outline pollutant allocations for the entire Little Osage watershed upstream of where the Marmaton River joins the Little Osage, including that portion of the watershed in Kansas. As stated in Section 7, wasteload allocations for Kansas are set at zero for the purposes of this TMDL. Tables 11, 13 and 15 outline allocations for only the Missouri portion of the Little Osage River watershed above the Marmaton River. Because there are no point sources in the Missouri portion of the watershed, no wasteload allocations are assigned and the TMDL load capacities and load allocations for each flow are equal. Because the Missouri portion of the Little Osage watershed accounts for 33 percent of the total watershed area, the allocations in Tables 11, 13, and 15 have been reduced from the overall allocations proportionally. Therefore, the allocations in Tables 11, 13 and 15 represent the pollutant loads for which Missouri is responsible.

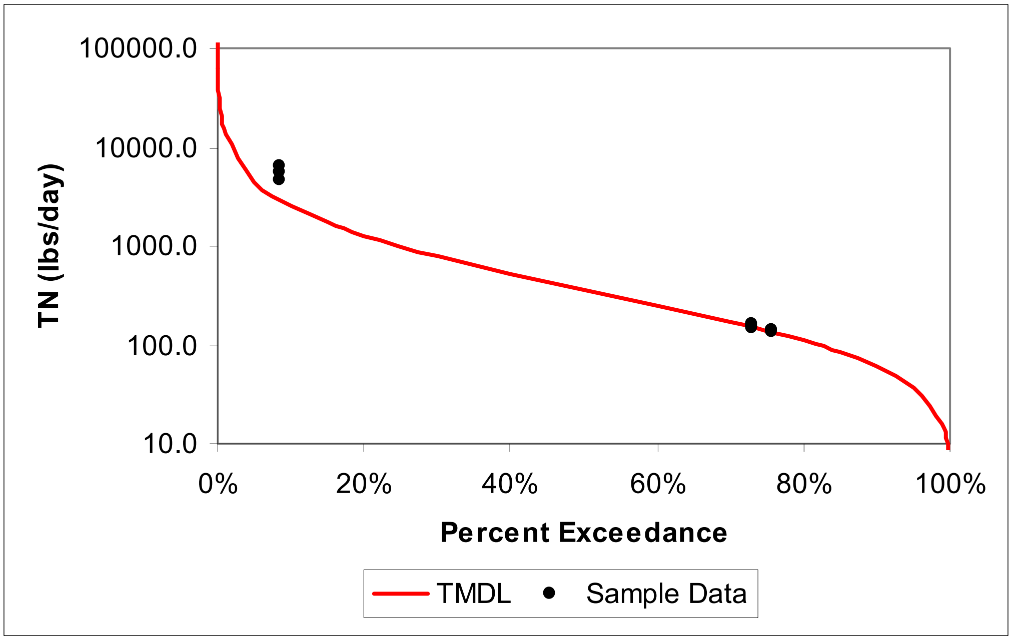

Figure 6. Total Nitrogen Load Duration Curve for Entire Little Osage Watershed (upstream of the Marmaton River).

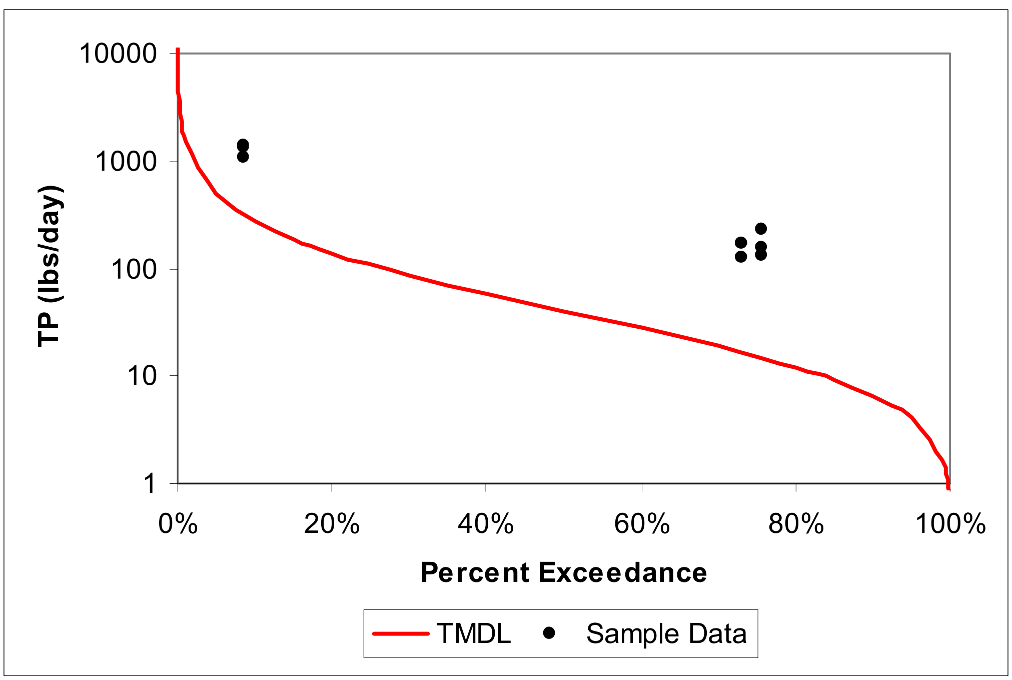

Figure 7. Total Phosphorus Load Duration Curve for Entire Little Osage Watershed (upstream of the Marmaton River).

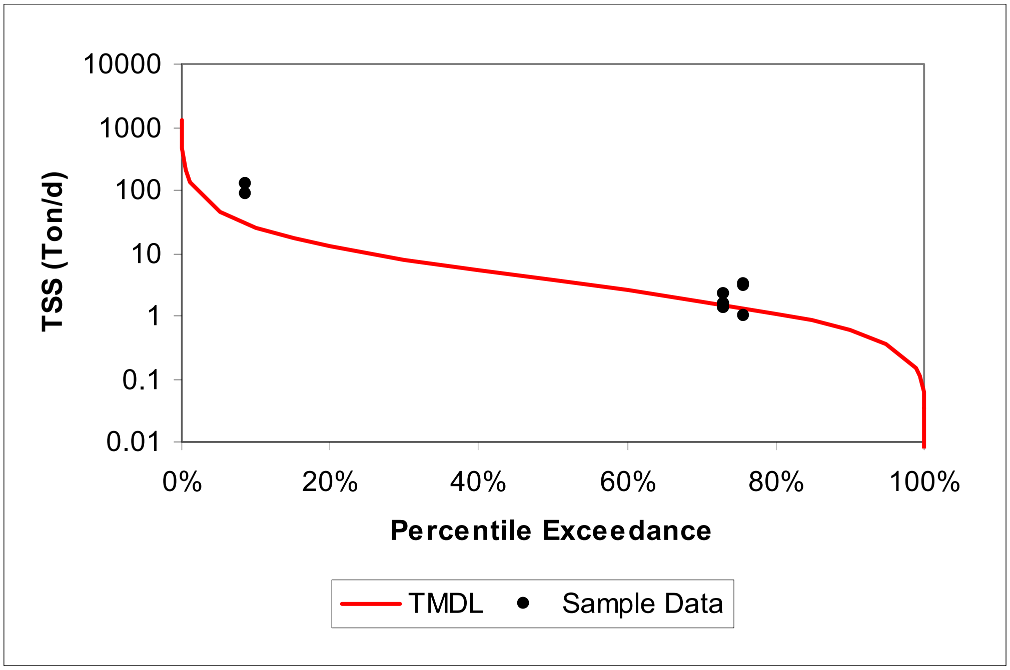

Figure 8. Total Suspended Solids Load Duration Curve for Entire Little Osage Watershed (upstream of the Marmaton River).

Table 10. Total Nitrogen Allocations (lbs/day) for Entire Little Osage Watershed (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TN TMDL (lbs/d)	TN LA (lbs/d)	TN sum WLA (lbs/d)
95%	8.2	37.4	37.4	0
90%	13.3	60.6	60.6	0
70%	38.1	172	172	0
50%	80.6	362	362	0
30%	175.0	783	783	0
10%	562.7	2510	2510	0
5%	1006.6	4487	4487	0

Table 11. Total Nitrogen Allocations (lbs/day) for Little Osage Watershed in Missouri (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TN TMDL (lbs/d)	TN LA (lbs/d)	TN sum WLA (lbs/d)
95%	2.7	12.3	12.3	0
90%	4.4	20	20	0
70%	12.6	56.6	56.6	0
50%	26.6	119.5	119.5	0
30%	57.8	258.4	258.4	0
10%	185.7	828.4	828.4	0
5%	332.2	1480.9	1480.9	0

Table 12. Total Phosphorus Allocations (lbs/day) for Entire Little Osage Watershed (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TP TMDL (lbs/d)	TP LA (lbs/d)	TP sum WLA (lbs/d)
95%	8.2	4.1	4.1	0
90%	13.3	6.6	6.6	0
70%	38.1	18.9	18.9	0
50%	80.6	40	40	0
30%	175.0	87	87	0
10%	562.7	279	279	0
5%	1006.6	500	500	0

Table 13. Total Phosphorus Allocations (lbs/day) for Little Osage Watershed in Missouri (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TP TMDL (lbs/d)	TP LA (lbs/d)	TP sum WLA (lbs/d)
95%	2.7	1.3	1.3	0
90%	4.4	2.2	2.2	0
70%	12.6	6.2	6.2	0
50%	26.6	13.2	13.2	0
30%	57.8	28.7	28.7	0
10%	185.7	92.2	92.2	0
5%	332.2	164.9	164.9	0

Table 14. Total Suspended Solids Allocations (Tons/day) for Entire Little Osage Watershed (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TSS TMDL (T/d)	TSS LA (T/d)	TSS sum WLA (T/d)
95%	8.2	0.4	0.4	0
90%	13.3	0.6	0.6	0
70%	38.1	1.7	1.7	0
50%	80.6	3.6	3.6	0
30%	175.0	7.9	7.9	0
10%	562.7	25.4	25.4	0
5%	1006.6	45.5	45.5	0

Table 15. Total Suspended Solids Allocations (Tons/day) for Little Osage Watershed in Missouri (upstream of the Marmaton River).

Percentile flow exceedance	Flow (cfs)	TSS TMDL (T/d)	TSS LA (T/d)	TSS sum WLA (T/d)
95%	2.7	0.12	0.12	0
90%	4.4	0.20	0.20	0
70%	12.6	0.57	0.57	0
50%	26.6	1.20	1.20	0
30%	57.8	2.61	2.61	0
10%	185.7	8.39	8.36	0
5%	332.2	15.0	15.0	0

9 Margin of Safety

A margin of safety is required in the TMDL calculation to account for uncertainties in scientific and technical understanding of water quality in natural systems. The margin of safety is intended to account for such uncertainties in a conservative manner. Based on EPA guidance, the margin of safety can be achieved through one of two approaches:

(1) Explicit - Reserve a portion of the load capacity as a separate term in the TMDL.
(2) Implicit - Incorporate the margin of safety as part of the critical conditions for the wasteload allocation and the load allocation calculations by making conservative assumptions in the analysis.

An implicit margin of safety was incorporated into the TMDL based on conservative assumptions applied to the QUAL2K model and used in the development of the TMDL load duration curves. Among the conservative approaches used was to calculate wasteload

allocations by targeting the 25th percentile of total suspended solids concentrations in the geographic region in which the Little Osage River is located, and to establish wasteload allocations under critical low flow conditions.

10 Seasonal Variation

A TMDL must consider seasonal variation in the derivation of the allocation. The Little Osage River TMDL addresses seasonal variation by identifying a loading capacity that is protective of the low flow period sampled in August 2008. QUAL2K TMDL development for low dissolved oxygen during critical low-flow conditions are expected to be protective year round.

The second way in which the Little Osage River TMDL takes seasonal variation into account is through the use of load duration curves. Load duration curves represent the allowable pollutant load under different flow conditions and across all seasons. The results obtained using the load duration curve method are more robust and reliable over all flows and seasons when compared with those obtained under critical low-flow conditions.

11 Monitoring Plan for TMDLs Developed under Phased Approach

Post-TMDL monitoring of all relevant water quality parameters will be scheduled and conducted by the Department approximately three years after the TMDL is approved, or in a reasonable period of time following the implementation of nonpoint source best management practices.

Additionally, the Department will routinely examine physical habitat, water quality, and invertebrate and fish community data collected by other state and federal agencies in order to assess the effectiveness of TMDL implementation. One example of such data is that generated by the Resource Assessment and Monitoring Program administered by the Missouri Department of Conservation. This program randomly samples streams across Missouri on a five- to six-year rotating schedule.

12 Implementation Plans

Due to issues regarding low dissolved oxygen as a natural background condition in prairie streams, the Department may develop revised dissolved oxygen criteria for the Little Osage River and similar streams during future triennial reviews of the Water Quality Standards. The Department acknowledges that, should revised criteria be developed, a revised Little Osage River TMDL may be necessary. It also acknowledges that the revised criteria may result in no difference for the Little Osage River and that new loading calculations may not differ or offer relief from what is currently contained in this TMDL.

12.1 Point Sources

As discussed in Section 3, there are no regulated point source contributions to the low dissolved oxygen impairment in the Missouri portion of the Little Osage watershed. The four

municipalities located within or partially within the watershed are very small and contain no permitted wastewater treatment facilities that discharge into the Little Osage watershed. Of the five permitted facilities in the Missouri portion of the watershed, three discharge downstream of the impaired segment and two – one general permit and one storm water permit – discharge to tributaries near the downstream end of the impaired segment. Given the location of these facilities and the conditions found in their operating permits, it is unlikely that either of these facilities contributes to the low dissolved oxygen problem in the impaired segment during critical low-flow periods.

Regardless, all permitted facilities within the Missouri portion of the impaired watershed will be inspected prior to next permit renewal to determine if best management practices or permit conditions are needed to ensure the facilities are not contributing nutrients or oxygen demanding substances to the Little Osage River. The inspections will include an assessment of the condition of the facilities and whether upgrades or additional measures are necessary.

As indicated in Section 1, the Little Osage River is on the state of Kansas' 2008 303(d) List for aquatic life impairments related to copper, lead, and dissolved oxygen. While there are a number of permitted point sources within the Kansas portion of the Little Osage watershed, including municipal wastewater treatment facilities and livestock operations, there are no data to attribute the impairment in Missouri to any of these facilities and the State of Missouri has no authority to regulate them in any case. However, the Department will notify the Kansas Department of Health and Environment upon completion of this TMDL and will remain committed to working with the State of Kansas to ensure that the Little Osage River meets water quality criteria at the state line.

Because of the lack of permitted facilities contributing to the low dissolved oxygen impairment in the Missouri portion of the Little Osage watershed, there are currently no wasteload allocations in this TMDL. As a result, no portion of the TMDL can be implemented through permit action at this time. In the event that a new point source is proposed to be established in the Little Osage watershed in the future, this TMDL will be reevaluated and the total load capacity reallocated to account for a new wasteload allocation. Any new permit issued by the Department will incorporate discharge limits set by the revised TMDL.

12.2 Nonpoint Sources

Because there are no pollutant reductions that can be achieved in the Little Osage watershed through control of permitted point sources, the implementation of this TMDL must be directed solely at nonpoint sources. This section will outline activities and practices currently being used to address potential nonpoint sources of pollutants and will suggest additional measures that could be implemented to control future nonpoint sources.

In November 2005, the Marais des Cygnes, Marmaton and Little Osage Rivers Citizens Watershed Committee was formed through the efforts of the Osage Valley Resource Conservation and Development Council. The aim of this committee was to facilitate a cooperative effort between residents within the Marais des Cygnes, Little Osage, and Marmaton

River watersheds to develop a comprehensive watershed management plan. The Little Osage River originates in Kansas and approximately two-thirds of the river lies therein. As stated in Section 1, the Marmaton River enters the Little Osage as a tributary just north of the city of Nevada and then the Little Osage joins the Marais des Cygnes to form the Osage River. The watershed committee is composed of county commissioners and Soil and Water Conservation District boards in Barton, Bates, Cass and Vernon Counties, plus interested watershed residents. Natural resource agencies and watershed residents from Kansas and Missouri were invited to provide ideas and technical expertise. Four public meetings were held in February and March, 2005 and July 2006 to obtain public input during development of the watershed management plan. Through this process, the following 10 issues and concerns were identified and prioritized:

- Erosion/soil loss.
- Solid waste management.
- Water quality and quantity.
- Public information.
- Quarries and other mines.
- Farmland conversion to residential land use.
- Habitat loss - aquatic and upland.
- Agricultural systems - concentrated animal feeding operation/animal feeding; Grazing/cropping systems.
- Private/Public Interaction.
- Residential/Urban.

The Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Management Action Plan was signed in August 2006 by Bates and Vernon County Commissioners, Bates and Vernon County Soil and Water Conservation Districts and the Osage Valley Resource Conservation and Development Council.

While there are no Section 319 Nonpoint Source projects[14] currently under way in Missouri to implement that section of the watershed management plan relating to the Little Osage River, the Citizens Watershed Committee has indicated that it is planning to initiate a proposal for such a project. In addition, in recent years there have been a number of nonpoint source best management practices, or BMPs, funded through cost-share and other programs and implemented in both Missouri and Kansas. BMPs are recommended methods, structures, and practices designed to prevent or reduce water pollution. The concept of BMPs is one of a voluntary and site-specific approach to water quality problems. Examples of practices recently put into place in the Little Osage watershed include establishment of permanent vegetative cover, construction of terraces and grass-lined waterways to reduce soil erosion, establishment of field borders, nutrient management, fencing to keep livestock away from streams, and inclusion of land in both the Conservation Reserve and Wetland Reserve Programs.

[14] These are projects intended to address nonpoint source pollution and are funded with grants administered by EPA Region 7 through the Department's Section 319 Nonpoint Source Implementation Program. Section 319 refers to Section 319(h) of the federal Clean Water Act.

To further reduce the loading and impact of nutrients and total suspended solids on the Little Osage River, additional efforts could be made to expand the number of acres where BMPs are utilized. Such efforts include encouraging more farmers to adopt agricultural BMPs, encouraging farmers utilizing BMPs to expand these practices, and working to assist farmers in securing funding to implement BMPs on their land. Along with expanding the BMPs noted above, other agricultural practices that could be implemented include improved irrigation and water management, establishment of riparian buffers and filter strips, implementation of enhanced cropping techniques (such as no-till agriculture), and additional enhanced grazing practices that prevent or mitigate livestock-caused damage to streams and riparian areas.

Further efforts may also be warranted to address the management of animal waste from feeding operations both inside and outside of the watershed – in particular, the application of waste as fertilizer on crop and pasture lands. Animal waste entering streams from surface runoff can contribute both nutrients and organic sediment that contribute to low dissolved oxygen. Although the Missouri Concentrated Animal Feeding Operation Nutrient Management Technical Standard adopted in March 2009 requires the development and implementation of field-specific Nutrient Management Plans, this regulation is specific only to on-site application of waste from Class I concentrated animal feeding operations with Missouri State Operating Permits. Waste originating from non-permitted feeding operations, or applied off-site from the feeding operation of origin, is not subject to this rule. Department guidelines outlining concentrated animal feeding operation BMPs specifically address land application of animal waste. Increased efforts to distribute these guidelines and encourage adoption of BMPs among both permitted and non-permitted facility operators represents an additional means to address loading of nutrients and organic sediment to the Little Osage River.

In an effort to most effectively implement these BMPs, the Department may work with the Natural Resources Conservation Service, or NRCS, and the local Soil and Water Conservation District to further encourage area farmers to implement these practices on their land. An additional approach may also be to work directly with the Marais des Cygnes, Marmaton and Little Osage Rivers Citizens Watershed Committee and the Osage Valley Resource Conservation and Development Council to assist in securing funding, through Section 319 Nonpoint Source grants and other sources, to implement pollution control strategies outlined in the current Watershed Management Action Plan. The Watershed Committee may also be an effective medium for securing and utilizing resources – in the form of both funding and volunteers – to implement water quality monitoring in order to track the progress of TMDL implementation.

In addition, personnel at the Water Management Division of the Kansas City District of the U.S. Army Corps of Engineers (personal communication, January 12, 2010), which regulates Truman Dam and Truman Reservoir, have indicated that backwater from Truman Reservoir may reach at least as far upstream on the Little Osage River as the stream gage at Horton, Mo. once every several years. Although this gage is approximately 2.4 miles downstream of the lower end of the impaired segment, it is possible that backwater from Truman Reservoir may occasionally impact the impaired segment of the Little Osage River. The Department does not have data at this time documenting the impact on sediment oxygen demand rates contributed by these flooding events, and this potential source of oxygen-consuming substances was not incorporated into the QUAL2K model. Further assessment of potential sources of sediment oxygen demand,

including backwater from Truman Reservoir, and the effects that these may have on water quality in the Little Osage River may be warranted in future iterations of this TMDL.

Finally, as noted in Section 5.1, water quality monitoring conducted for this TMDL indicates that dissolved oxygen levels at Site 3 (Highway V) are generally lower than dissolved oxygen measured at sites further downstream. This suggests that the stretch of the Little Osage River between the Kansas-Missouri state line and this site may be a critical area in which to pinpoint and address contributing sources of low dissolved oxygen and oxygen-consuming substances. Additional water quality monitoring and source identification of low dissolved oxygen conditions may be warranted in this stretch of the river, as might a collaboration with the Kansas Department of Health and Environment in order to identify and address any possible sources that may be contributing from upstream.

13 Reasonable Assurances

The Department has the authority to issue and enforce Missouri State Operating Permits. For TMDLs that address point sources of pollution, effluent limits determined from TMDL wasteload allocations incorporated into a state permit, along with effluent monitoring reported to the Department, should provide a reasonable assurance that instream water quality standards will be met. In the case of the Little Osage River, however, there are no permitted point source contributions to the impairment and, hence, no opportunity to set regulatory effluent limits.

Since "reasonable assurance" in reference to TMDLs is generally intended to address only point sources, any assurances that nonpoint source contributors of low dissolved oxygen will implement measures to reduce their contribution in the future will not be found in this section. Instead, discussion of reduction efforts relating to nonpoint sources can be found in Section 12, "Implementation Plans", of this TMDL.

14 Public Participation

Much public effort went into writing the Marais des Cygnes, Marmaton and Little Osage Rivers Watershed Management Plan. As mentioned in Section 13.2, this effort included four public meetings in 2005 and 2006 where ten major issues and concerns were identified and prioritized.

This water quality-limited segment of the Little Osage River is included on Missouri's 2008 303(d) List of impaired waters. The public notice period for the draft Little Osage River TMDL was from November 13, 2009 to December 28, 2009. Groups that received the public notice announcement included the Missouri Clean Water Commission, the Department's Water Quality Coordinating Committee, the Missouri Department of Conservation's Policy Coordinating Unit, Stream Team volunteers in the area, the Bates County and Vernon County Soil and Water Conservation Districts, the Bates County and Vernon County Commissions, the Osage Valley Resource Conservation and Development Council, and the state legislators representing Bates and Vernon Counties. In addition, since the Little Osage River originates in Kansas and flows into Missouri, a public notice announcement was also sent to the Kansas Department of Health

and Environment, Bureau of Water. Finally, the public notice, the TMDL Information Sheet, and this document were posted on the Department website, making them available to anyone with Internet access. Comments received, and the Department's response to those comments, have been placed in the Little Osage River TMDL administrative record, as noted below.

15 Administrative Record and Supporting Documentation

An administrative record on the Little Osage River TMDL has been assembled and is being kept on file with the Department. It includes the following:

- Biological Assessment Report, Little Osage River, Vernon County, October 2006 – March 2007, Missouri Department of Natural Resources, Environmental Services Program
- Marais des Cygnes Basin Total Maximum Daily Load (Little Osage River), Approved August 28, 2001, Kansas Department of Health and Environment
- Little Osage Sub-basin Rapid Watershed Assessment, USDA Natural Resources Conservation Service, 2008
- A Watershed Conditions Report for the State of Kansas HUC 10290103 (Little Osage) Watershed, Kansas Department of Health and Environment Bureau of Water
- The Marias des Cygnes, Marmaton, and Little Osage Rivers Watershed Management Plan, 2006
- Watershed Restoration and Protection Strategy for the Marais des Cygnes Basin, Lake Region Resource Conservation and Development Council, 2003
- Effects of Impoundments and Land Cover Changes on Stream flows and Selected Fish Habitat in the Upper Osage River Basin, Missouri and Kansas, U.S. Geological Survey, 2007
- Stream Team survey data from Bates and Vernon Counties
- QUAL2K input and output files
- Load duration curve modeling files
- Little Osage River TMDL Information Sheet
- Public notice announcement

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Appendix A
Little Osage River Water Quality Data
Appendix A.1 – Historic Data
Collected by Missouri. Dept. of Natural Resources, Kansas Dept. of Health and Environment and U.S. Army Corps of Engineers, Kansas City District 2000-2008

Org.	Site	Site Name	Year	Month	Day	Time	Temp	DO	pH	SC	TKN	NH3-N	NO23-N	TN	TP	TSS	BOD
							deg C	mg/L		µS/cm	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	1	6	1215	3	12.5	8	505		0.03	0.52		0.07	14	0.499
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	2	3	1250	5	13.7	8.4	435		0.02	0		0.05	21	5.82
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	3	9	1235	14	9.5	8.3	448		0.0099	0		0.1	41	3.93
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	4	5	940	13	10.5	8.3	449		0.0099	0.14		0.05	27	2.7
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	5	4	1235	21	7.7	8.1	484		0.0099	0		0.09	46	1.14
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	6	7	1035	23	8.2	8.2	400		0.0099	0.06		0.13	46	4.38
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	7	6	1250	29	6.1	8.2	417		0.0099	0.37		0.1	45	2.46
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	8	9	1040	28	4.2	7.7	422		0.0099	0.15		0.09	23	1.56
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	11	2	1255	17	4	7.5	363		0.0099	0		0.137	6	2.04
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2000	11	29	1030	5	10	7.7	372		0.0099	0		0.07	5	3.54
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2001	3	7	940	6	11.6	7.9	470		0.0099	2.54		0.07	18	1.2
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2001	5	2	910	22	8.6	8	423.6		0.0099	0		0.056	24	2.22
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2001	7	11	1005	28	6.5	7.9	409.5		0.0099	0.05		0.143	44	1.23
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2001	9	6	945	25	5.8	7.7	360		0.022	0.05		0.091	27	1.41
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2001	10	31	1005	13	5.5	7.4	309		0.0099	0.02		0.111	11	2.49
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2002	2	6	913	4	11.9	7.8	378.2	0.673	0.0099	0.52	1.19	0.111	13	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2002	4	3	955	10	9.1	8.1	472.9	0.631	0.0499	0.07	0.7	0.088	17	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2002	6	5	1218	23	6.7	7.7	453.8	0.53	0.0499	0.3	0.63	0.113	37	
COEKC	3652/17.1	L. Osage R. @ Hwy. V	2002	7	29	1200	27.5	3.1	7.5	679	0.22	0.00499	0.0099	0.23	0.17	32	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2002	8	7	1015	27	4.1	7.3	401.5	0.317	0.0499	0.07	0.39	0.116	10	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2002	10	9	1006	16	7.6	7.6	356.6	0.0499	0.0499	0.07	0.12	0.071	13	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	1	8	906	4	8.8	7.6	492.3	0.355	0.0499	0.07	0.42	0.087	4.99	

Org.	Site	Site Name	Year	Month	Day	Time	C	DO	pH	SC	TKN	NH3N	NO3N	TN	TP	TSS	BOD
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	3	5	952	1	12.4	8	379.6	0.767	0.0499	0.35	1.12	0.086	18	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	5	7	916	18	7	7.4	289.4	1.716	0.0499	0.41	2.13	0.381	252	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	7	9	925	27	4.7	7.4	422.3	0.357	0.0499	0.07	0.43	0.088	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	9	10	936	23	6.7	8.1	262.2	0.853	0.0499	0.6	1.45	0.129	25	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2003	11	5	923	10	5.6	7.6	376.7	0.44	0.0499	0.0499	0.51	0.066	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2004	4	7	901	15	9.3	7.6	454	0.36	0.0499	0.36	0.72	0.06	20	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2004	6	9	910	24	6.6	7.9	434	0.19	0.0499	0.0499	0.24	0.08	25	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2004	8	4	934	26	6.4	7.5	397	0.31	0.0499	0.19	0.5	0.1	14	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2004	10	6	855	15	7.1	7.3	382	0.31	0.0499	0.0499	0.36	0.1	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2004	12	8	849	7	10.3	7.5	317	0.75	0.0499	0.0499	0.8	0.14	34	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2005	3	9	1046	8	11.4	8	463	0.14	0.0499	0.0499	0.19	0.03	10	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2005	5	4	913	14	8.9	8	466	0.17	0.0499	0.11	0.28	0.03	12	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2005	7	13	919	26	5.3	7.5	417	0.36	0.0499	0.0499	0.51	0.34	18	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2005	9	14	919	22	7.4	7.1	158	1.53	0.0499	0.21	1.74	0.62	692	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2005	11	9	930	15	4.3	7.2	492	0.1	0.0499	0.0499	0.15	0.11	10	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2006	2	1	922	8	10.4	7.5	540	0.18	0.0499	0.0499	0.23	0.03	13	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2006	4	5	1004	16	8	7.5	465	1.22	0.0499	0.0499	1.27	0.09	37	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2006	6	7	1030	26	5	7.4	330	0.67	0.0499	0.17	0.84	0.12	34	
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	25	1730		3.8									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	25	1100	25.5	0.8									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	26	545	26.3	2.6									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	26	1645		3.9									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	27	2330	26.4	2.2									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	27	0		3.6									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	28	845	25.8	1.9									
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	7	28	0		2.4									
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2006	8	9	955	28	4.8	7.3	382	1.04	0.0499	0.0499	1.09	0.25	14	

Org.	Site	Site Name	Year	Month	Day	Time	C	DO	pH	SC	TKN	NH3N	NO3N	TN	TP	TSS	BOD
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2006	10	3	1050	19	2.8	7.7	527		0.01499	0.02	0.49	0.07		
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2006	11	29	908	13	7.2	7.3	602	0.85	0.11	0.0499	0.9	0.1	67	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	1	10	830	4	10.5	7.2	329	0.7	0.0499	0.0499	0.75	0.07	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	3	7	833	9	12.2	8	401	0.71	0.0499	0.0499	0.76	0.05	11	
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2007	3	16	1045	11.5	6.8	7.5	432		0.01499	0.00499	0.43	0.06		
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	5	9	910	19	7.6	7.5	309	0.76	0.0499	0.47	1.23	0.26	150	
COEKC	3652/17.1	L. Osage R. @ Hwy. V	2007	5	23	1930					0.51	0.022	0.04	0.55	0.0725	21.6	
COEKC	3652/17.1	L. Osage R. @ Hwy. V	2007	6	13	1025					0.93	0.0224	0.37	1.3	0.385	564	
COEKC	3652/17.1	L. Osage R. @ Hwy. V	2007	7	11	1020					0.34	0.0183	0.41	0.75	0.0942	26.4	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	7	11	831	26	6.5	7.7	412	0.5	0.0499	0.35499	0.85499	0.09	18	
COEKC	3652/17.1	L. Osage R. @ Hwy. V	2007	8	29	1530					0.43	0.0216		0.43	0.098	13.6	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	9	12	835	19	6.5	7.4	458	0.6	0.0499	0.07489	0.67489	0.14	30	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2007	10	31	852	13	8	7.3	386	0.4	0.0499	0.07489	0.47489	0.07	20	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2008	4	9	843	10	10	7.7	266	1.9	0.0499	0.34499	2.24499	0.48	510	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2008	6	4	854	24	7.4	7.5	439	0.5	0.0499	0.44499	0.94499	0.08	29	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2008	8	6	901	26	6.5	7.3	332	0.8	0.0499	0.07489	0.87489	0.2	143	
MDNR	3652/17.1	L. Osage R. @ Hwy. V	2008	10	7	1130	19.3	5	7.8	643		0.01499	0.1	0.36	0.04		
MDNR	3652/0.2	L. Osage R. @CR 1325	2008	10	7	1435	17.6	5.9	7.9	587		0.01499	0.07	0.36	0.06		
MDNR	3652/9.0	L. Osage R. @CR 800	2008	10	8	1035	15	7	7.6	673		0.01499	0.07	0.34	0.04		
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2008	10	8	901	16	8.1	7.2	497	0.3	0.0499	0.07489	0.37489	0.05	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2008	12	3	920	5	12.9	7.6	515	0.2	0.0499	0.07489	0.27489	0.03	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2009	1	7	906	4	12.7	7.4	515	0.3	0.0499	0.21499	0.51499	0.04	4.99	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2009	3	4	926	6	13.5	7.6	506	0.43	0.1		0.526	0.04	10	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2009	5	13	938	19	9.1	7.4	443	0.38	0.1		1.101	0.091	49	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2009	7	21	1001	24	6.8	7.4	298	1.02	0.1		1.664	0.154	68	
KDHE	3652/6.0	L. Osage R. nr Fulton, KS	2009	11	18	942	9	10.4	7.2	367	0.56	0.1		0.877	0.082	24	

See notes and definitions of abbreviations on the following page.

Additional information below regarding the available Little Osage River water quality data.

Sampling Entity	Type of Data	Used for Modeling?
MoDNR	QA	No
KDHE	QA	No

Notes:

QA = These data are of sufficient quality to evaluate compliance with water quality standards and to support TMDL development because they were collected in accordance with required quality assurance procedures and Department sampling protocols.

Empty cell means no data available.
BOD = Biochemical Oxygen Demand
C = temperature in degrees Celsius
DO = Dissolved Oxygen
Hwy = Highway
KDHE = Kansas Department of Health and Environment
SC = Specific Conductivity
MoDNR = Missouri Department of Natural Resources
NH3N = Ammonia as N
NO3N =nitrate +nitrite as nitrogen
nr. = near
Org. = Organization name
TKN = Total Kjeldahl Nitrogen
TN = Total Nitrogen
TP = Total Phosphorus
TSS = Total Suspended Solids

Detection limits and non-detects are expressed as "less-than" numbers and show up in this list as those data ending in 99. Example: <2 will appear as 0.99.

Appendix A.2

Suspended solids and instantaneous discharge for reference targeting
Data collected by USGS and provided by EPA

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
USGS 06918070 Osage River above Schell City, MO				
11/8/1989	1400		1.2	0.16
1/11/1990	802			0.08
3/8/1990	8470		3	0.14
5/8/1990	5360		1.4	0.15
7/12/1990	1080		1	0.09
9/6/1990	1.4		1	0.1
5/8/1991	1210		2	0.22
7/18/1991	540		0.39	0.17
9/5/1991	500		2.3	0.16
11/5/1991	200		0.66	0.07
1/9/1992	720		2.3	0.1
3/3/1992	380		1.4	0.1
5/6/1992	500		1.4	0.07
7/9/1992	16000		1.3	0.5
9/2/1992	300			0.07
11/19/1992	13700		1.5	0.34
1/12/1993	4160		1.3	0.07
3/10/1993	6440		1.5	0.13
5/5/1993	7740		1.6	0.14
7/27/1993	45300		1.2	0.26
9/28/1993	48200		0.78	0.15
11/29/1994	13900	270	1.7	0.28
3/7/1995	1430		1.1	0.11
4/13/1995	1860		1.2	0.17
5/16/1995	13900		1.4	0.13
6/27/1995	45400	140	1.6	0.14
8/22/1995	822	82	1.5	0.15
11/7/1995	228	30		0.1
4/1/1996	226		1.1	0.12
5/7/1996	15500		7.5	1.4
6/19/1996	5960	480	2.8	0.46
8/6/1996	493		1.4	0.16
11/5/1996	2110	50	0.82	0.08
3/4/1997	15400		1.9	0.19
4/15/1997	27800		2.7	0.36
5/13/1997	1100		1.3	0.14
6/24/1997	2480	190	1.8	0.18
8/13/1997	80		1.1	0.08
11/6/1997	401	31		
6/8/1998	545	150		
3/9/1999	13300		3.1	0.7
4/6/1999	1150			0.1
5/17/1999	18600		1	0.07
6/7/1999	7920	195	1.6	0.25

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
8/25/1999	148			0.14
11/1/1999	253	21		0.12
3/20/2000	8830		2.6	0.39
4/11/2000	662			0.1
5/22/2000	300	61	0.91	0.13
6/5/2000	385		1.5	0.17
7/24/2000	3560		2.3	0.67
11/27/2000	177	11	0.86	0.07
3/21/2001	9090		3.1	0.28
4/18/2001	2720		1.8	0.19
5/21/2001	5450		4	0.64
6/13/2001	5080		1.4	0.22
11/28/2001	185	24		0.09
3/11/2002	621	50	0.82	0.09
4/15/2002	949	183	1.1	0.26
5/22/2002	6400	49	1.5	0.16
6/17/2002	5600	252	1.8	0.35
7/24/2002	229	E 90[1]	1.2	0.17
11/6/2002	93	13		0.05
3/17/2003	538	75	1.3	0.13
4/15/2003	211	78		0.15
5/13/2003	2700	426	2.6	0.47
6/17/2003	1220	188	2	0.3
7/9/2003	524	120	1.3	0.2
11/4/2003	113	32		0.08
3/9/2004	44000	164	2.5	0.56
4/19/2004	860	49		0.1
5/11/2004	783	62	0.97	0.12
6/7/2004	567	83	1.2	0.17
7/21/2004	2310	130	1.2	0.22
11/15/2004	5000	109	1.5	0.31
3/28/2005	1950	35	1.3	0.08
4/12/2005	3780	432	1.4	0.38
5/24/2005	3130	256	2.4	0.33
6/28/2005	7400	120	1.5	0.29
7/25/2005	1600	178	1.4	0.27
11/28/2005	159	23		0.07
3/22/2006	792	36	0.99	0.11
4/19/2006	330	76	0.85	0.15
5/22/2006	2590	172	1.6	0.29
6/20/2006	259	68	1.2	0.16
11/13/2006	37	18	0.8	0.06
2/26/2007	6430	264	3.1	0.58
3/6/2007	1880	156	2.4	0.41
4/16/2007	21700	560	3	0.67
5/7/2007	20500	370	2.7	0.59
6/26/2007	2420	156	1.6	0.25
7/24/2007	8320	448	2	0.6
11/5/2007	179	58	1.2	0.17

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
3/17/2008	3400	111	1.2	0.13
4/22/2008	4330	108	1.4	0.17
5/28/2008	19900	532	2.8	0.74
6/3/2008	15700	456	2.6	0.63
7/21/2008	785	50	1.2	0.13
10/14/2008	587	55	0.67	0.14
3/17/2009	4140	152	1.3	0.2
4/7/2009	7560	96	1.6	0.17
5/19/2009	14400	176	1.6	0.31
6/2/2009	2440	140	1.3	0.21
USGS 06919500 Cedar Creek near Pleasant View, MO				
10/14/2008	8.8	< 15[2]	E 0.33[1]	E 0.03[1]
11/3/2008	13	< 15[2]		E 0.03[1]
12/1/2008	16	< 15[2]	E 0.32[1]	E 0.04[1]
1/26/2009	34	< 15[2]	0.35	E 0.03[1]
2/3/2009	37	< 15[2]	0.24	E 0.03[1]
3/17/2009	66	< 15[2]		E 0.03[1]
4/7/2009	235	< 15[2]	0.73	0.04
5/19/2009	430	< 30[2]	1.2	0.1
6/2/2009	106	< 15[2]	1	0.06
10/14/2008	8.8	< 15[2]	E 0.33[1]	E 0.03[1]
11/3/2008	13	< 15[2]		E 0.03[1]
12/1/2008	16	< 15[2]	E 0.32[1]	E 0.04[1]
1/26/2009	34	< 15[2]	0.35	E 0.03[1]
2/3/2009	37	< 15[2]	0.24	E 0.03[1]
3/17/2009	66	< 15[2]		E 0.03[1]
4/7/2009	235	< 15[2]	0.73	0.04
5/19/2009	430	< 30[2]	1.2	0.1
6/2/2009	106	< 15[2]	1	0.06
USGS 06919925 Brush Creek above Collins, MO				
5/25/1994	13			< 0.01[1]
9/21/1994	0.39			0.02
5/23/1995	62			0.01
USGS 06921590 South Grand River at Archie, MO				
6/14/2007	49	22	1.8	0.13
7/13/2007	59	30	1.7	0.13
9/13/2007	5.2	12	2.1	0.16
11/30/2007	4.1	< 10[2]	3.2	0.45
1/17/2008	61	15	1.8	0.16
3/20/2008	579	128	2.4	0.22
5/14/2008	280	180	1.8	0.3
7/23/2008	14	17	1	0.09
9/11/2008	11	27	0.92	0.17
10/9/2008	13	< 15[2]	0.71	0.09
1/6/2009	121	< 15[2]	1.3	0.06
3/27/2009	200	130	1.3	0.17
5/19/2009	118	40	1.4	0.14
USGS 06921720 Big Creek near Blairstown, MO				
10/9/2008	11	78		0.21

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
11/4/2008	62		0.85	0.17
3/24/2009	198	324	1.2	0.34
5/19/2009	218	76	1.8	0.2
USGS 06922190 West Fork Tebo Creek near Lewis, MO				
10/13/1989	1			0.07
11/9/1989	1			0.03
12/7/1989	1			0.04
1/11/1990	1			0.02
2/8/1990	2.7			0.03
3/8/1990	9.3		0.6	0.03
4/4/1990	9.6			0.03
5/7/1990	9.6		1	0.04
6/7/1990	9.5		0.7	0.03
7/12/1990	9.6		1.8	0.07
8/10/1990	9			0.04
9/6/1990	1		0.8	0.06
10/16/1990	1			< 0.01[2]
11/7/1990	1			0.02
12/5/1990	1			0.02
1/9/1991	1			0.02
3/6/1991	1			0.02
4/17/1991	1			0.03
5/7/1991	8		1.4	0.08
6/4/1991	1		1.5	0.03
7/18/1991	0.1			0.07
8/12/1991	0			0.13
9/6/1991	0			0.14
USGS 3844410942043 South Trib. Muddy Creek nr Harrisonville, MO				
4/29/1992	0.19	20		0.02
5/20/1992	0.03	32	1.1	0.05
6/17/1992	0	132		0.24
8/27/1992	0.03		1.7	0.12
9/29/1992	0.05			0.07
11/4/1992	0.1		1.2	0.08
12/8/1992	0.13		0.9	0.13
1/27/1993	1.6		1.1	0.24
2/24/1993	0.2		0.7	0.08
3/24/1993	0.5		1.1	0.05
USGS 3845250942233 Muddy Creek nr Harrisonville, MO				
4/30/1992	0.14	31		0.01
5/20/1992	0.24	40	2.3	0.04
8/27/1992	0.01		2.5	0.47
12/8/1992	0.11		1.8	0.06
1/27/1993	1.7		2.7	0.22
2/24/1993	0.12		1.4	0.02
3/24/1993	0.13		1	0.03
USGS 3846130942231 North Trib. Muddy Creek nr Harrisonville, MO				
4/29/1992	0.48	9		0.03
5/20/1992	0.15	6	1.1	0.02

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
6/17/1992	0.03	9	0.88	0.03
8/27/1992	0.03		0.6	0.06
11/4/1992	0.27		2.6	0.8
12/8/1992	0.77		3.1	0.1
1/27/1993	3.5		2.6	0.25
2/24/1993	0.52		3.3	0.16
3/24/1993	0.56		2.8	0.08
USGS 06921582 South Grand River below Freeman, MO				
1/14/1998	95	10		
6/1/1998	112	1		
8/20/1998	3.6	23		
11/18/1998	76	14	1.1	0.07
12/3/1998	150		0.81	0.19
1/26/1999	56	12	1.3	0.07
2/24/1999	84		0.97	E 0.05[1]
3/24/1999	56		0.46	E 0.04[1]
4/14/1999	60		E 0.33[1]	< 0.05[2]
5/17/1999	995		3	0.7
6/16/1999	27	92	2	0.2
7/28/1999	4.4			0.1
8/11/1999	4.2	22	0.69	0.1
9/15/1999	6.3		0.58	0.07
10/21/1999	4			0.09
11/8/1999	3.5	12		0.18
12/8/1999	34		1.2	0.17
1/5/2000	11	3	1.2	0.09
2/16/2000	5.8		0.94	0.08
3/14/2000	12		0.6	0.09
4/11/2000	11		0.5	0.07
5/23/2000	16	75	1	0.14
6/13/2000	15		0.99	0.17
7/18/2000	4.2	37		0.14
8/17/2000	0.89			0.12
9/13/2000	0.53			0.14
10/19/2000	2.1		2.7	0.36
11/20/2000	2.4	< 10[2]	0.83	0.13
12/12/2000	1.7		1.4	0.15
1/16/2001	10	22	4.1	0.54
3/1/2001	94		3.9	0.12
3/21/2001	84		3	0.12
4/11/2001	648		3.4	0.81
5/9/2001	32	73	1.4	0.18
6/21/2001	952		3.6	1.12
7/18/2001	8.3	56	0.94	0.13
8/14/2001	1.8		0.69	0.12
9/6/2001	1.1		1.4	0.17
10/17/2001	46	61	1.3	0.23
11/13/2001	3.7	16	E 0.62[1]	0.15
12/18/2001	4.9	20	1.2	0.11

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
1/23/2002	3.8	12	2.3	0.21
2/20/2002	125	82	1.4	0.19
3/4/2002	22	< 10[2]	0.94	0.08
4/23/2002	120	160	2	0.24
5/15/2002	239	108	1.7	0.2
6/11/2002	19	40	0.98	0.1
7/10/2002	1.6	40		0.11
8/13/2002	8.2	41	0.9	0.16
9/25/2002	0.62	23	1.1	0.09
10/21/2002	1.3	10	E 0.47[1]	0.07
11/14/2002	0.95	< 10[2]	E 0.58[1]	0.12
12/13/2002	1.4	< 10[2]		0.08
1/7/2003	1.5	22		0.13
2/11/2003	1.5	28	2	0.41
3/5/2003	1.9	24	4.5	0.6
3/7/2003	1.5			
3/7/2003	1.5			
4/10/2003	2.8	28	E 1.1[1]	0.15
5/30/2003	2.8	36		0.15
6/19/2003	3.8	43	1.1	0.17
7/23/2003	0.35	17		0.17
8/22/2003	0.12	12		0.18
9/23/2003	1.2	12	1	0.13
11/10/2003	2.9	11		0.09
1/13/2004	8.3	< 10[2]	1.9	0.13
2/23/2004	23			
3/10/2004	107	44	2.5	0.13
5/7/2004	24	30		0.11
7/20/2004	17	44	1.2	0.17
9/22/2004	18	60	1.5	0.23
11/3/2004	105	38	1.2	0.21
1/11/2005	412	56	1.6	0.16
3/22/2005	39	13		0.1
5/6/2005	16	16	E 0.51[1]	0.07
7/22/2005	12	44	0.69	0.11
9/30/2005	8	25	1.4	0.16
11/15/2005	3.8	15		0.24
1/13/2006	3.6	< 10[2]	1.8	0.19
2/27/2006	3			
3/17/2006	14	37	0.79	0.18
5/17/2006	15	29	0.94	0.1
7/14/2006	28	92	1.6	0.29
9/11/2006	2.1	39	1	0.17
11/27/2006	1.5	17	0.6	0.18
1/12/2007	12	11	1.7	0.16
2/9/2007	31	14	2.9	0.29
3/28/2007	33	42	1	0.15
4/17/2007	194	90	1.8	0.15
5/4/2007	1380	600	3.1	0.75

Date	Flow (cfs)	TSS (mg/L)*	TN (mg/L)	TP (mg/L)
USGS 06920580 Weaubleau Creek near Collins, MO				
5/8/2007	111	13	0.53	E 0.03[1]

[1] Estimated value modifier - estimate was used in calculations.
[2] Less than value modifier - one half of less than value was used in calculations.
* Data was originally recorded as nonfilterable residue (NFR) by the U.S. Geological Survey. This has been changed to total suspended solids (TSS) for consistency within this document. NFR and TSS are synonymous.

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Appendix B
Development of Suspended Solids Targets Using Reference Load Duration Curves

Overview

This procedure is used when a lotic[15] system is placed on the 303(d) List for a pollutant and the designated use being addressed is aquatic life. In cases where pollutant data for the impaired stream is not available a reference approach is used. The target for pollutant loading is the 25th percentile calculated from all data available within the ecological drainage unit (EDU) in which the water body is located. Additionally, it is also unlikely that a flow record for the impaired stream is available. If this is the case, a synthetic flow record is needed. In order to develop a synthetic flow record calculate an average of the log discharge per square mile of USGS gaged rivers for which the drainage area is entirely contained within the EDU. From this synthetic record develop a flow duration from which to build a load duration curve for the pollutant within the EDU.

From this population of load durations follow the reference method used in setting nutrient targets in lakes and reservoirs. In this methodology the average concentration of either the 75th percentile of reference lakes or the 25th percentile of all lakes in the region is targeted in the TMDL. For most cases available pollutant data for reference streams is also not likely to be available. Therefore follow the alternative method and target the 25th percentile of load duration of the available data within the EDU as the TMDL load duration curve. During periods of low flow the actual pollutant concentration may be more important than load. To account for this during periods of low flow the load duration curve uses the 25th percentile of EDU concentration at flows where surface runoff is less than 1 percent of the stream flow. This result in an inflection point in the curve below which the TMDL is calculated using load calculated with this reference concentration.

Methodology

The first step in this procedure is to locate available pollutant data within the EDU of interest. These data along with the instantaneous flow measurement taken at the time of sample collection for the specific date are recorded to create the population from which to develop the load duration. Both the date and pollutant concentration are needed in order to match the measured data to the synthetic EDU flow record.

Secondly, collect average daily flow data for gages with a variety of drainage areas for a period of time to cover the pollutant record. From these flow records normalize the flow to a per square mile basis. Average the log transformations of the average daily discharge for each day in the period of record. For each gage record used to build this synthetic flow record calculate the Nash-Sutcliffe statistic to determine if the relationship is valid for each record. This relationship must be valid in order to use this methodology. This new synthetic record of flow per square

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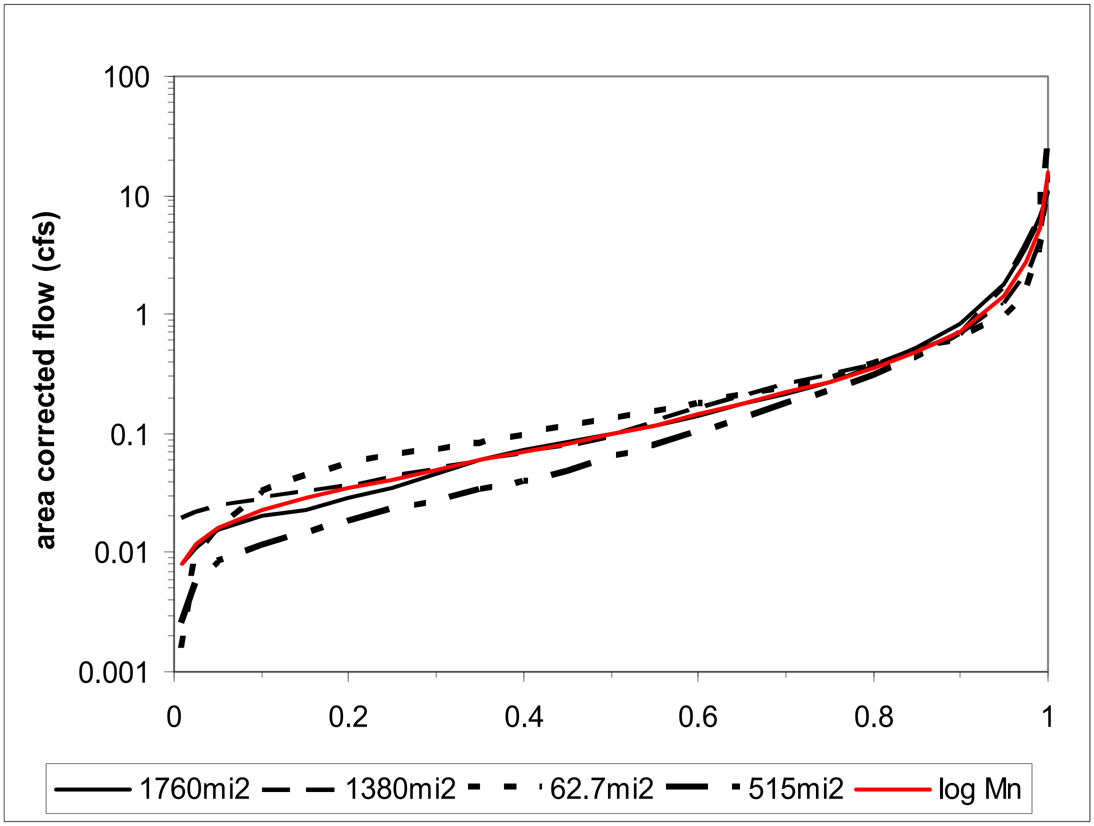
[15] Lotic = pertaining to moving water

mile is used to develop the load duration for the EDU. The flow record should be of sufficient length to be able to calculate percentiles of flow.

The following examples show the application of the approach to one Missouri EDU.

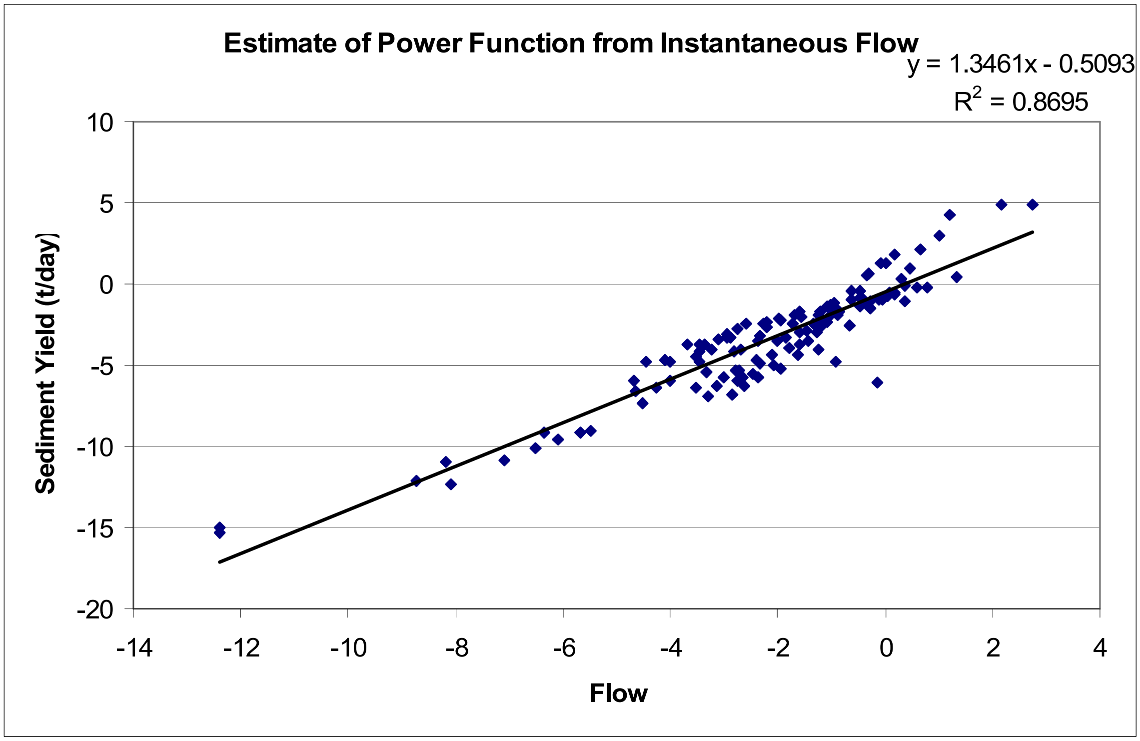
The watershed-size normalized data for the individual gages in the EDU were calculated and compared to a pooled data set including all of the gages. The results of this analysis are displayed in the following figure and table:



Gage	gage	area (mi^2)	normal Nash-Sutcliffe	lognormal Nash-Sutcliffe
Platte River	06820500	1760	80%	99%
Nodaway River	06817700	1380	90%	96%
Squaw Creek	06815575	62.7	86%	95%
102 River	06819500	515	99%	96%

This demonstrates the pooled data set can confidently be used as a surrogate for the EDU analyses.

The next step is to calculate pollutant-discharge relationships for the EDU, these are log transformed data for the yield (tons/mi^2/day) and the instantaneous flow (cfs/mi^2.) The following graph shows the EDU relationship:



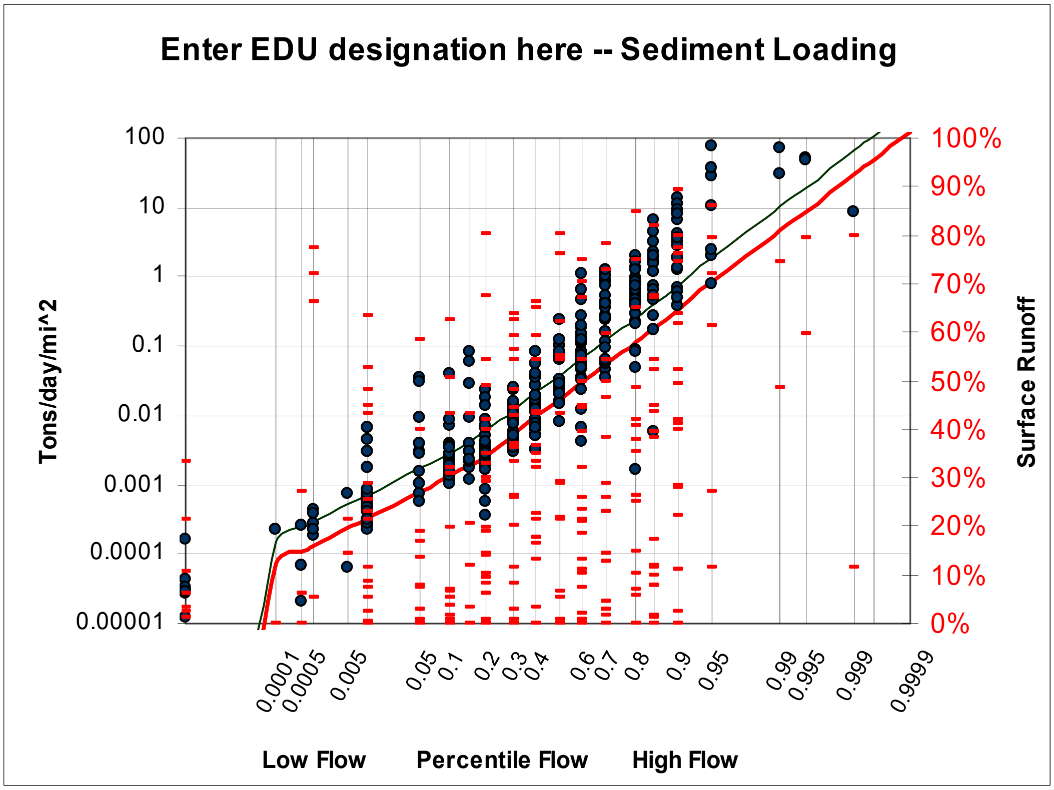
Further statistical analyses on this relationship are included in the following Table:

m	1.34608498	b	-0.509320019
Standard Error (m)	0.04721684	Standard Error (b)	0.152201589
r^2	0.86948229	Standard Error (y)	1.269553159
F	812.739077	DF	122
SSreg	1309.94458	SSres	196.6353573

The standard error of y was used to estimate the 25 percentile level for the TMDL line. This was done by adjusting the intercept (b) by subtracting the product of the one-sided Z_{75} statistic times the standard error of (y). The resulting TMDL Equation is the following:

*Sediment yield (t/day/mi^2) = exp (1.34608498 * ln (flow) - 1.36627)*

A resulting pooled TMDL of all data in the watershed is shown in the following graph:



To apply this process to a specific watershed would entail using the individual watershed data compared to the above TMDL curve that has been multiplied by the watershed area. Data from the impaired segment is then plotted as a load (tons/day) for the y-axis and as the percentile of flow for the EDU on the day the sample was taken for the x-axis.

Appendix C
Little Osage River Water Quality Model

I. Model Setup

QUAL2K is a steady-state stream water quality model that primarily simulates dissolved oxygen and water quality parameters that influence diurnal dissolved oxygen fluctuations. It assumes that the major transport mechanisms are significant only in the direction of flow. QUAL2K conceptualizes a river system as a sequence of completely mixed reactors or computational elements. As a steady-state model, it is fairly limited in characterizing river systems where transient conditions are significant.

A QUAL2K model was developed for the Little Osage River. The model was calibrated for the flow and water quality data measured on August 27, 2008. The succeeding sections outline the details of the model setup, model inputs, calibration, and simulation results.

Hydraulics. QUAL2K allows the input of the hydraulic characteristics of a river as empirical relations of mean water depths, velocities and flow widths as power functions of discharge. In the absence of stream measurements during the sampling period, depths and velocities as functions of discharge for Little Osage were developed using the historical rating measurements of the USGS gages in the river. The depth-discharge and velocity-discharge functions were developed from recent rating measurements for the gages at Little Osage near Horton, MO (USGS06917060) and Little Osage near Fulton, KS (USGS0691700). Table 1 shows the set of river hydraulic characteristics derived from the analysis of the USGS rating measurements.

Table 1. Hydraulic characteristics at USGS gage locations in Little Osage River.

Little Osage Gages	**Drainage Area sq.mi.**	**Velocity (mps)**		**Depth (m)**	
		Coefficient	**Exponent**	**Coefficient**	**Exponent**
Near Fulton	295	0.2933	0.2205	0.5246	0.3509
Near Horton	498	0.1211	0.3602	0.6568	0.4192

River Discretization. The model domain for Little Osage is the segment beginning from the USGS gage near Fulton, KS and extends to the USGS gage near Horton, MO (See Figure 4 in Section 5.1 of TMDL document). The domain was discretized into 116 computational segments with an average length of 500 meters. The summary of the basin and reach characteristics is shown in Table 2.

Table 2. Little Osage modeled sub-basins and reach characteristics (see Figure 1).

Basin	Area sq.mi.	Flow Type[1]	Flow to Reach	Reach Length (mi.)
1	8.1	Uniform Lateral	1	3.74
2	14.1	Tributary		
3	12.6	Tributary	2	1.93
4	6.0	Uniform Lateral	3	4.17
5	35.0	Tributary		
6	15.3	Uniform Lateral	4	5.57
7	7.4	Tributary		
8	8.0	Uniform Lateral	5	3.21
9	7.1	Tributary		
10	16.2	Tributary	6	5.84
11	4.8	Uniform Lateral		
12	3.2	Uniform Lateral	7	3.35
13	6.4	Tributary		
14	25.0	Tributary		
15	10.4	Tributary	8	2.67
16	15.6	Tributary	9	4.65
17	6.8	Uniform Lateral		

[1] *Tributary modeled as point source flow, uniform lateral as diffuse flow.*

Boundary Conditions and Lateral Inflows. The upstream boundary of the Little Osage model is the USGS gage near Fulton, KS. For modeling purposes, the lateral inflows (both tributary and diffuse) to the modeled segments were estimated using a mass balance between the flows at the USGS gages near Fulton, KS and Horton, MO. For the simulation period, the net lateral inflow into the modeled reaches was estimated as the difference between the flows measured at the gages. This flow was then proportioned to the various contributing sub-basins based on drainage area. Figure 1 shows the mean daily flows recorded at the USGS gages near Fulton, KS and Horton, MO for August 2008. On August 27, 2008, the daily flows at the gages were 3.8 cfs and 11 cfs, respectively.

Meteorological Forcing Functions. Hourly data from the automated weather station in Lamar in Barton County, MO were used to develop the meteorological forcing functions for the models. Although there is a NWS cooperative weather station at the Nevada WWTP, MO only daily data for temperature is available through the National Climate Data Center. The water quality model requires hourly data for air temperature, dew point, wind speed and cloud cover.

Water Quality. The water quality parameterization was based on the results of the single-station diurnal dissolved oxygen analysis. In addition, the model requires specification of the loadings at the upstream and tributary/point sources. Tributary and diffuse loadings were estimated based on historical measurements in the basins and in an adjacent basin (Marmaton River). The summary of historical water quality measurements on the main stem and tributaries of the Little Osage and Marmaton rivers (spreadsheets from MoDNR, c/o Bill Whipps) served as basis for deriving loading inputs. Sensitivity analysis of the calibration model indicated that errors in specifying the loading inputs do not have a major impact on the diurnal dissolved oxygen fluctuation as

compared to the sediment oxygen demand (SOD). Kinetic rate coefficients used in the model where initially specified following suggested values in the literature (e.g. Bowie et. al, 1985). The values were adjusted as necessary in the calibration run to get reasonable match between measured and simulated water chemistry.

II. Model Calibration

The Little Osage model was calibrated using the measured data on August 27, 2008. Water chemistry data for August 25, 2008 were used to set the initial conditions of the calibration run. In general, the calibration process involved estimating the SOD that could account for the diurnal fluctuation of dissolved oxygen at the sampling sites. Based on the single-station analysis of the continuous dissolved oxygen measurements, results indicated that benthic processes may contribute significantly to the fluctuation of dissolved oxygen observed under critical low flow conditions. Preliminary model runs indicated that the contribution of water column processes seems to be small relative to the contribution of benthic processes in explaining the observed variability of dissolved oxygen at the sampling sites. It should be noted that prior to the sampling period, oxygen demanding materials may have accumulated in the system. The continuous accumulation and decay of oxygen-demanding materials in the benthos cannot be represented in a steady-state model. QUAL2K cannot represent the temporal changes in SOD due to varying flow and loading conditions prior to a specific steady-state run. Moreover, since QUAL2K does not allow initialization of the benthic process, SOD was prescribed for the calibration run. The SOD rate was adjusted until a reasonable match between simulated and measured diurnal dissolved oxygen curve is obtained. The calibrated SOD is about 4.45 g O_2/m^2/day for the sampling sites in Little Osage.

Although water chemistry data were available from the spring sampling, the Little Osage model was not validated with those data. High flows during the spring sampling, which was conducted on the intervening days between major storm events, preclude a validation model for that period. For the purposes of this study, the Marmaton River water quality model (described in another report) will serve as the validation model.

Simulation Results. The modeling results are summarized in Table 3 and Figures 2 through 4. For each site, model predictions of dissolved oxygen were compared with the observed data. In comparing model predictions with observed data, it should be noted that the model predictions are average concentrations for a given computational reach while the measured data are instantaneous values at specific locations. Qualitative comparisons were made as compared to more rigorous quantitative assessments using statistical approaches. Table 3 and Figure 3 show that the water quality model did fairly well in simulating the diurnal dissolved oxygen data at the sampling sites. Deviations of the dissolved oxygen model predictions (minimum, maximum and mean diurnal dissolved oxygen) for the Little Osage sites were within 5 percent of the measured data. The comparison of the model predicted longitudinal variation of dissolved oxygen with the measured data is shown in Figure 4.

III. Model Application

However, for the modeling purposes and in order to set appropriate upstream boundary conditions, the upstream flow used was 0.12 cfs. This corresponds to the observed flow at Fulton on August 9, 2006 where corresponding water chemistries were measured at the Kansas monitoring station, SC207 (see Table 6). Nonpoint source loadings for the contributing areas on the Kansas side of the modeling domain were taken from the average measurements at SC207 during low flow conditions (measurements where flow is less than 1.7 cfs, see Table 6).

Ecoregion values were used for the nutrient loadings from the Missouri subbasins contributing to the Little Osage river. For the Central Irregular Plains Level III Ecoregion, the nutrient values are 0.855 mg/l for TN, 0.092 mg/l for TP, and 2.8 ug/l for Chlorophyll-A.

Using the ecoregion nutrient loadings, simulation results shows that about 82% SOD reduction is required in Little Osage River in order to meet the DO standard. The simulated longitudinal profile of DO with the SOD reduction shows that beginning from the KS-MO state line (about 41.5 km) up to the downstream boundary, the simulated minimum DO is equal to or greater than 5.0 mg/l.

Table 3. Comparison of model predicted and simulated dissolved oxygen.

	Site 1		**Site 2**		**Site 3**	
	Data	**Model**	**Data**	**Model**	**Data**	**Model**
Little Osage Dissolved Oxygen, mg/L						
Minimum	4.58	4.60	4.31	4.11	3.23	3.32
Error (%)	*0.02 (0.3%)*		*-0.20 (-4.5%)*		*0.09 (2.7%)*	
Maximum	5.64	5.83	5.17	5.41	4.36	4.38
Error (%)	*0.19 (3.5%)*		*0.24 (4.6%)*		*0.02 (0.6%)*	
Mean	5.02	4.09	4.63	4.61	3.71	3.70
Error (%)	*0.07 (1.4%)*		*-0.02 (-0.4%)*		*-0.01 (-0.3%)*	

Table 4. Water quality data from KDHE monitoring site SC207 (near Fulton, KS)

Date	Time	Flow* cfs	DO mg/l	BOD_5 mg/l	NH_3 mg/l	NO_3 mg/l	TKN mg/l	OrthoP mg/l	TP mg/l	TSS mg/l	TOC mg/l
6/7/2000	1035	2.9	8.2	4.38	0.0099	0.06	0.530	0.0099	0.130	46	
7/6/2000	1250	31	6.1	2.46	0.0099	0.37	0.810	0.0099	0.100	45	
8/9/2000	1040	1.7	4.2	1.56	0.0099	0.15	0.390	0.0099	0.090	23	
7/11/2001	1005	5	6.5	1.23	0.0099	0.05	0.100	0.0099	0.143	44	5.70
6/5/2002	1218	85	6.7	***0.16*****	0.0499	0.27	0.569	0.12499	0.099	38	2.69
6/5/2002	1223	85	6.7	***0.25***	0.0499	0.29	0.491	0.12499	0.127	36	2.91
8/7/2002	1015	0.7	4.1	***0.49***	0.0499	0.10	0.317	0.12499	0.116	10	3.51
7/9/2003	0925	1.6	4.7	***0.75***	0.0499	0.10	0.357	0.12499	0.088	10	4.13
6/9/2004	0910	18	6.6	***0.58***	0.0499	0.0499	0.190	0.12499	0.079	25	3.72
8/4/2004	0934	34	6.4	***0.95***	0.0499	0.19	0.307	0.12499	0.098	14	4.61
7/13/2005	0919	4.1	5.3	***2.41***	0.0499	0.0499	0.357	0.12499	0.341	18	8.19
6/7/2006	1030	38	5.0	***1.14***	0.0499	0.17	0.666	0.12499	0.123	34	5.09
8/9/2006	0955	0.12	4.8	***1.95***	0.0499	0.0499	1.039	0.12499	0.254	14	7.05
7/11/2007	0831	93	6.5	***0.50***	0.0499	0.33	0.468	0.12499	0.089	18	3.52
6/4/2008	0854	122	7.4	***0.76***	0.0499	0.42	0.454	0.12499	0.081	29	4.16
8/6/2008	0901	57	6.5	***2.09***	0.0499	0.10	0.779	0.12499	0.200	143	7.41

* flow at the USGS gage near Fulton, KS.

** estimated using relationship with TOC developed by KDHE (BOD_5=-0.946+0.4103*TOC)

NOTE: Detection limits and non-detects are expressed as "less-than" numbers and show up in this list as those data ending in 99. Example: <0.02 will appear as 0.0099.

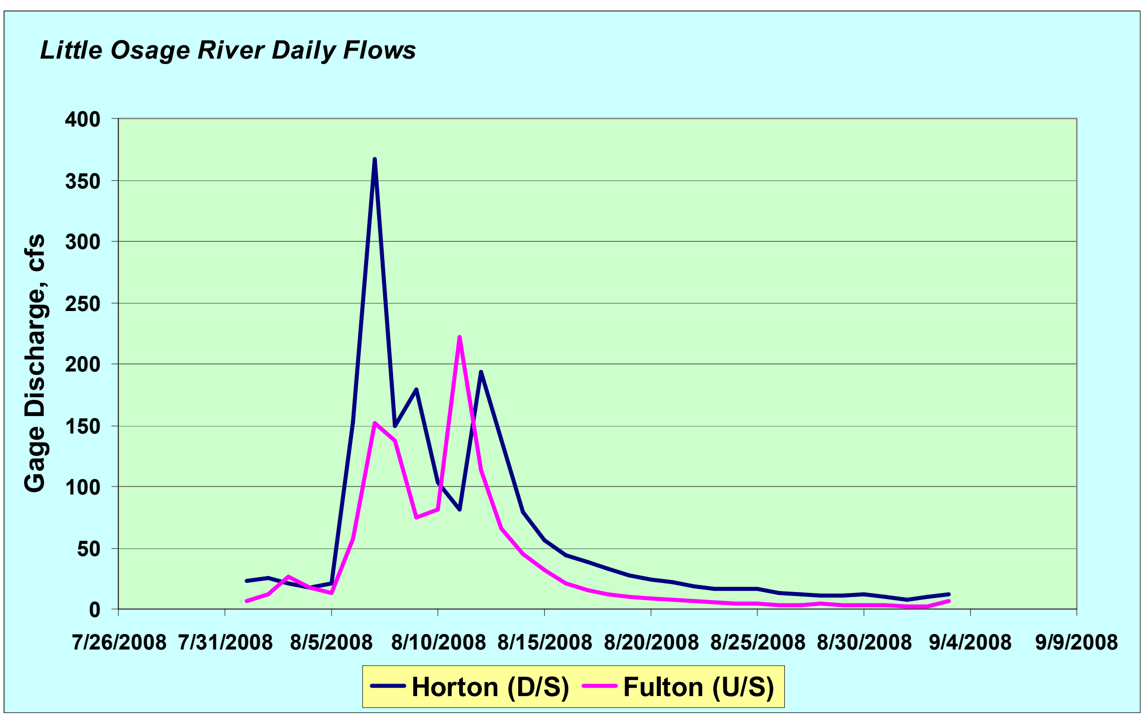


Figure 1. Mean daily flows at the USGS gages near Horton, MO and Fulton, KS.

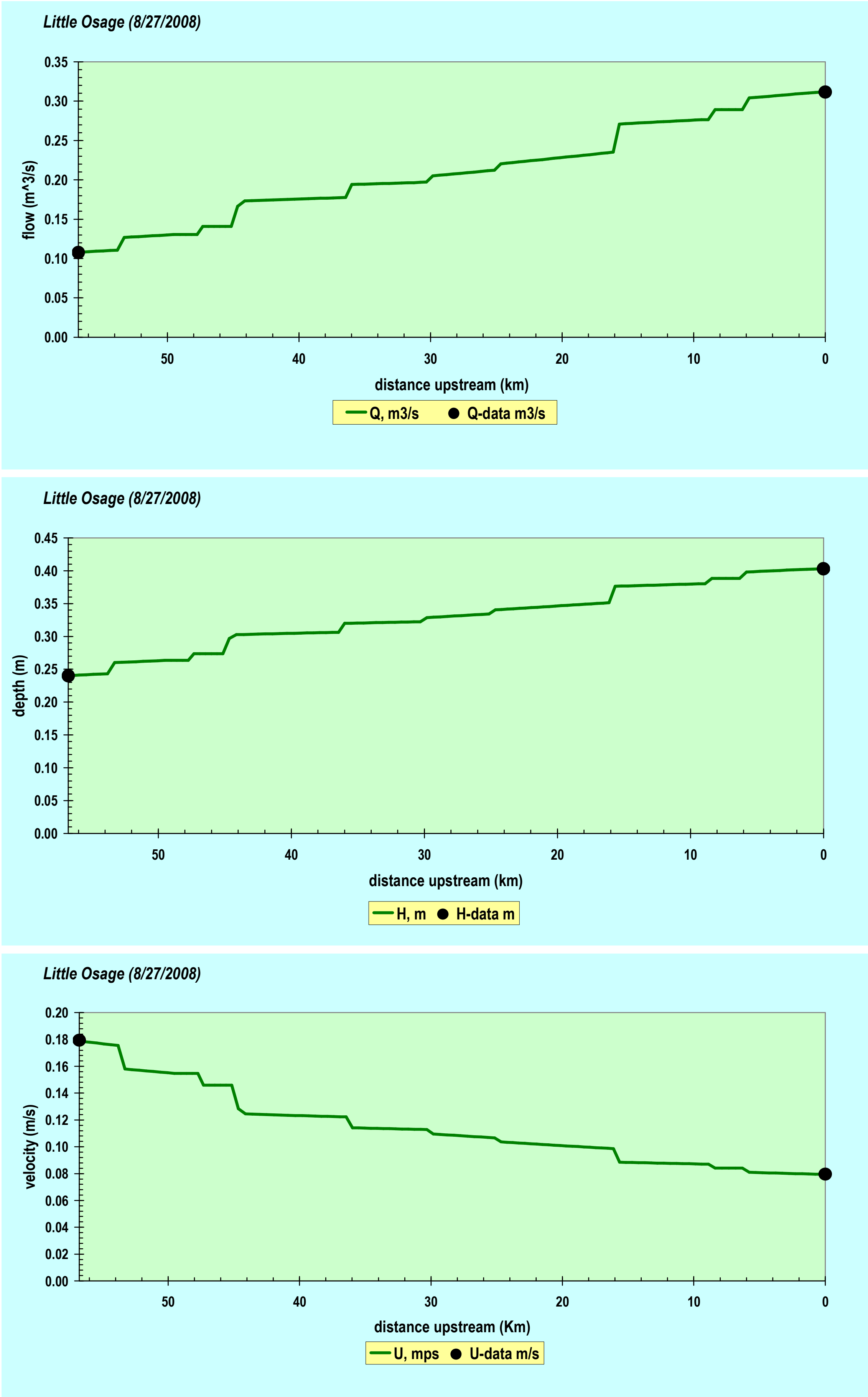


Figure 2. Measured and predicted flow, depths and velocities for Little Osage River

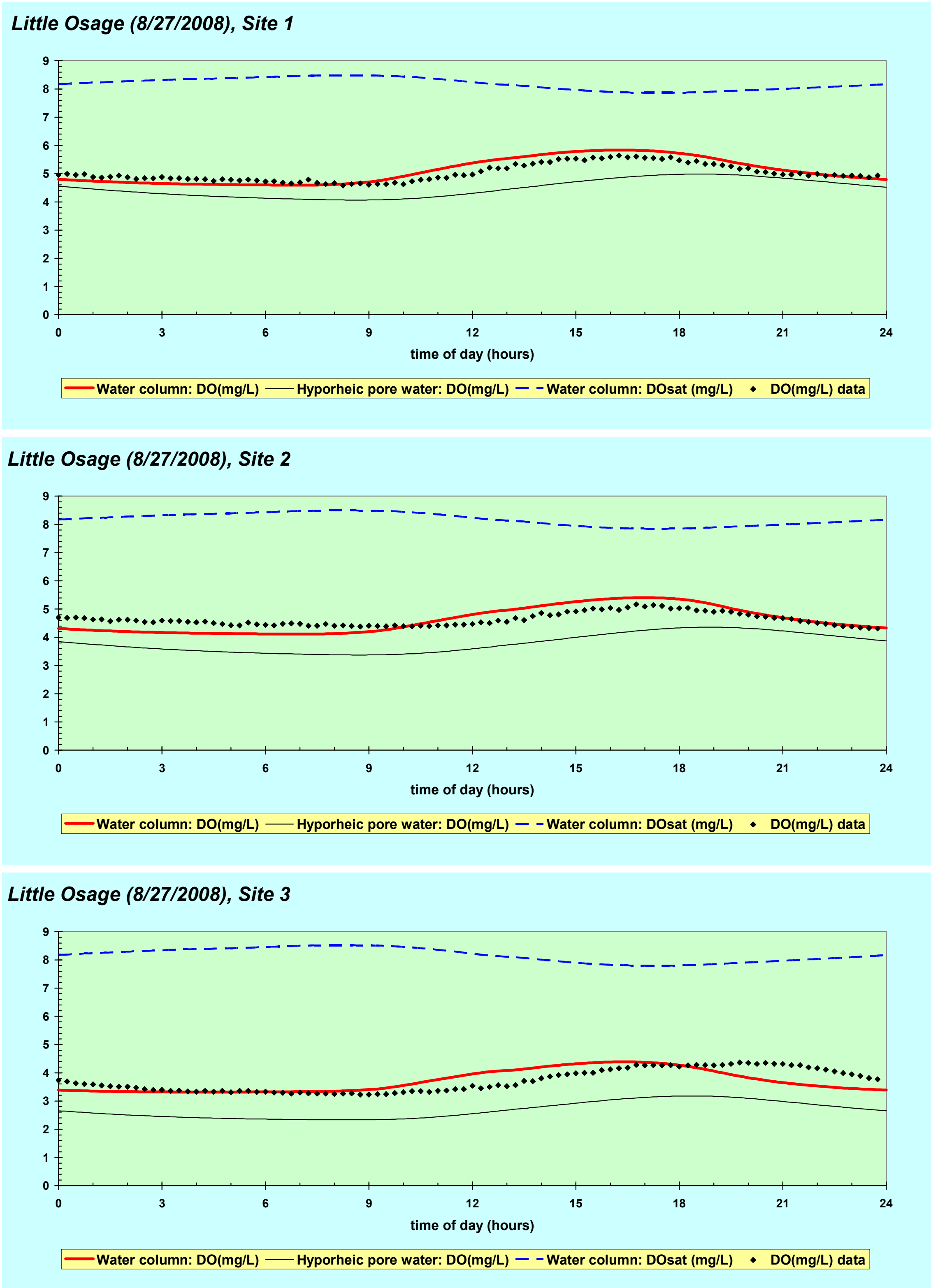


Figure 3. Comparison of measured and model predicted DO for Little Osage sites.

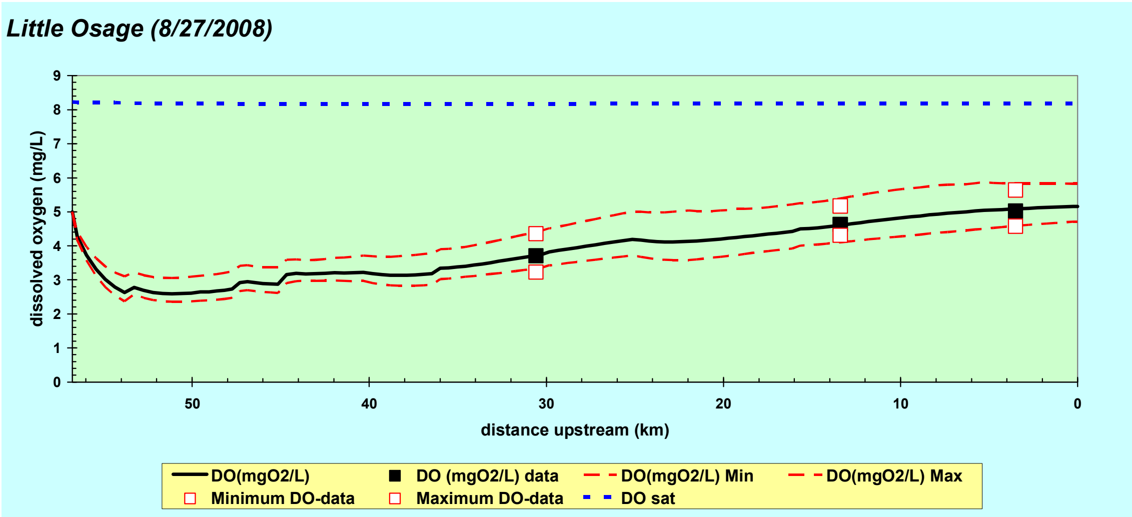


Figure 4. Model predicted longitudinal variation in DO in the Little Osage River.

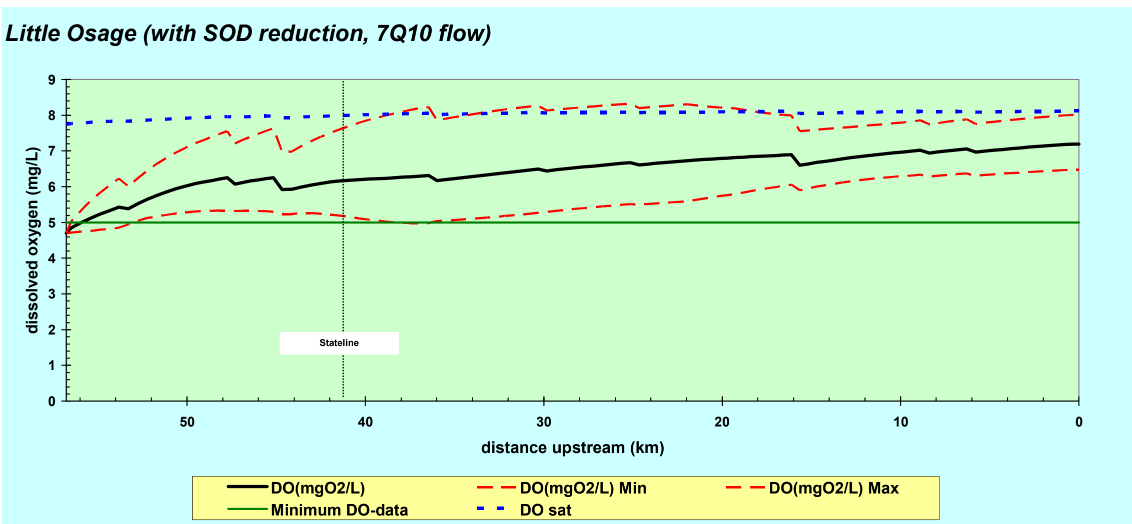


Figure 5. Model predicted longitudinal variation in DO in the Little Osage River with a reduction in SOD.